

List of Acronyms

AEO	Annual Energy Outlook	kW-yr	Kilowatt Year
ASU	Air Separation Unit	LAER	Lowest Available Emissions Rate
BACT	Best Available Control Technology	LM	Load Management
BTU	British Thermal Unit	LNG	Liquefied Natural Gas
CCPI	Clean Coal Power Initiative	LWR	Light Water Reactor
CFB	Circulating Fluidized Bed	MACT	Maximum Achievable Control Technology
CO	Carbon Monoxide	Mgal/d	Million gallons per day
CO ₂	Carbon Dioxide	MMBtu	Million British Thermal Units
COE	Cost of Electricity	MMTCE	Million Metric Tons of Carbon-Equivalent
Co-Op	Co-Operative	Mtons	Million Tons
CRS	Congressional Research Service	Muni	Municipality
DG	Distributed Generation	MW	Megawatt
DOE	Department of Energy	MWhr	Megawatt Hour
ECBM	Enhanced Coal Bed Methane	NAAQS	National Ambient Air Quality Standards
EERE	Energy Efficiency and Renewable Energy	NEI	Nuclear Energy Institute
EIA	Energy Information Administration	NEMS	National Energy Modeling System
EIS	Environmental Impact Statement	NETL	National Energy Technology Laboratory
EPA	Environmental Protection Agency	NG	Natural Gas
EPRI	Electric Power Research Institute	NGCC	Natural Gas Combined Cycle
EOR	Enhanced Oil Recovery	NIMBY	Not-In-My-Backyard
EPC	Engineering, Procurement, and Construction	NO _x	Nitrogen Oxide
FGD	Flue Gas Desulfurization	NPC	National Petroleum Council
GHG	Greenhouse Gas	NREL	National Renewable Energy Laboratory
GPA	Grade Point Average	NSR	New Source Review
GTC	Gasification Technologies Council	O&M	Operating and Maintenance
GW	Gigawatts	OTM	Oxygen Transport Membrane
H ₂	Hydrogen	PC	Pulverized Coal
Hg	Mercury	Petcoke	Petroleum Coke
HHV	High Heat Value	PP&E	Property, Plant, and Equipment
HRSG	Heat Recovery Steam Generator	PPM	Parts per Million
IGCC	Integrated Gasification Combined Cycle	PUC	Public Utilities Commission
IGFC	Integrated Gasification Fuel Cell	PV	Present Value
IOU	Investor-Owned Utility	PURPA	Public Utility Regulatory Policies Act
IPP	Independent Power Producer	Quad	Quadrillion British Thermal Units
ITM	Ion Transport Membrane	R&D	Research and Development
JETRO	Japan Petroleum Institute	ROI	Return on Investment
kW	Kilowatt	RTO	Regional Transmission Organization
kWhr	Kilowatt Hour		

SCOHS	Selective Catalytic Oxidation of Hydrogen Sulfide	SROI	Social Return on Investment
SCPC	Supercritical Pulverized Coal	SWOT	Strengths, Weaknesses, Opportunities, and Threats
SCR	Selective Catalytic Reduction	Syngas	Synthesis or Synthetic Gas
SO _x	Sulfur Oxide	WPSC	Wisconsin Public Service Commission
SO ₂	Sulfur Dioxide		

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<http://www.powerthefuture.net/filings/octechhear.htm>

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Appendix A: Workshop Participation List

This appendix lists the participants in one or more of the workshops held in conjunction with this study.

Amick, Phil	ConocoPhillips
Bedick, Robert C.	U.S. Department of Energy – NETL
Berg, David R.	Office of Climate Change Policy - DOE
Cathro, Doug L.	Air Liquide Process & Construction, Inc.
Childress, James	Gasification Technologies Council
Childress, Robert	Gasification Technologies Council
Cicero, Daniel	U.S. Department of Energy – NETL
Clayton, Stewart	U.S. Department of Energy – NETL
Cook, Dexter	Consultant
Cortez, Douglas H.	Fluor
Crouse, Floyd	U.S. Department of Energy – NETL
DeLallo, Michael	Parsons Infrastructure & Technology
Denton, David	Eastman Gasification Services Company
Derenne, Steve	WE Power
Drnevich, Raymond	Praxair
Fisher, Jennifer H.	ChevronTexaco Worldwide Power & Gasification
Garabetta, Ralph	U.S. Department of Energy – NETL
Geertsema, Ari	Center for Applied Energy Research
Graves, H.H.	Global Energy, Inc.
Gray, David	Mitretek Systems
Heaven, David L.	Fluor
Hennekes, Robert	Shell Global Solutions B.V.
Holt, Neville	Electric Power Research Institute (EPRI)
Hooper, Max	Uhde Corporation of America
Horton, Robert	Chevron Texaco Worldwide Power & Gasification
Jones, Robert M.	General Electric Company
Kosstrin, Herbert	R.W. Beck, Inc.
Kubek, Daniel J.	UOP
Ludlow, Chris	U.S. Department of Energy – NETL
Mollot, Darren	U.S. Department of Energy
Maxwell, Russ	U.S. Department of Energy – NETL
McClanahan, Tim S.	Tennessee Valley Authority
McConnell, Chuck	Praxair
McGurl, Gil	U.S. Department of Energy – NETL
Morehead, Harry	Siemens Westinghouse Power Corporation
Moreton, Bruce	Bechtel

Mudd, Michael J.	American Electric Power
Narula, Ram	Bechtel
Olliver, Richard	ConocoPhillips
Paterson, Andrew	U.S. Department of Energy
Perry, Mildred B.	U.S. Department of Energy – NETL
Philcox, Jack	Philcox Professionals
Ramezan, Massood	SAIC
Rath, Larry	U.S. Department of Energy – NETL
Rich, John	WMPI
Robart, Andrew	Siemens Westinghouse Power Corporation
Rush, Randall	Southern Company
Salerno, Salvatore	Mitretek Systems
Salinas, Leo	Dow Chemical Company
Schloesser, Lynn	Eastman Chemical Company
Shaffer, Frank	U.S. Department of Energy – NETL
Sorensen, James C.	Air Products & Chemicals, Inc.
Stiegel, Gary J.	U.S. Department of Energy – NETL
Strakey, Joe	U.S. Department of Energy – NETL
Sturm, Karl	ChevronTexaco
Tam, Samuel S.	Nexant, Inc./A Bechtel Affiliated Company
Tennant, Jenny	U.S. Department of Energy – NETL
Thomas, Greg	Air Liquide America LP
Todd, Douglas M.	Process Power Plants LLC
Toshima, Hiroshi	Japan Petroleum Institute (JETRO)
Watanabe, Tetsuji	Japan Petroleum Institute (JETRO)
Watari, Ryuzo	Chlyoda Corporation
White, Tim	Leucadia
Wooten, John M.	Peabody Group

Appendix B:

Technical Input Data and Assumptions

This appendix contains the input data for the modeling assumptions discussed in Chapter 4, for IGCC, PC, NGCC, distributed generation, and fuel cells. All costs are stated in 2003 dollars.

Parameter	Units	Current Regulatory Framework Snapshot	Current Regulatory Framework - Moderate Progression	Current Regulatory Framework - Advanced Progression	Multi- Regulation - Moderate Progression	Multi- Pollutant Regulation - Advanced Progression	Multi- Pollutant Plus Carbon Regulation - Moderate Progression	Multi- Pollutant Plus Carbon Regulation - Advanced Progression
Plant Size	MW	550	550	550	550	550	550	550
Lead Time	Yr	4	4	4	4	4	4	4
Overnight Capital Cost in 2003	\$2003/kW	1400	1400	1400	1470	1470	1870	1870
Overnight Capital Cost in 2025	\$2003/kW	1400	1100	900	1102	902	1502	1302
Heat Rate in 2003	Btu/kW-Hr	8427	8427	8427	8461	8461	9939	9939
Efficiency (HHV) in 2003		40.5%	40.5%	40.5%	40.3%	40.3%	34.3%	34.3%
Heat Rate in 2025	Btu/kW-Hr	8427	7400	5688	7400	5688	8507	6320
Efficiency (HHV) in 2025		40.5%	46.1%	60.0%	46.1%	60.0%	40.1%	54.0%
Fixed O&M cost in 2003	\$2003/kW-yr	33.8	33.8	33.8	34.5	34.5	39.7	39.7
Fixed O&M cost in 2025	\$2003/kW-yr	33.8	33.8	33.8	33.8	33.8	39.1	39.1
Variable O&M (ex fuel) in 2003	\$2003 \$/MW- Hr	4.0	4.0	4.0	4.0	4.0	4.6	4.6
Variable O&M (ex fuel) in 2025	\$2003 \$/MW- Hr	4.0	3.6	2.7	3.6	2.7	4.2	3.2
SO ₂ Removal Rate	%SO ₂ Removed	99%	99%	99.5%	99%	99.5%	99%	99.5%
NO _x Emissions	lbNO _x /mmBtu	0.07	0.07	0.02	0.02	0.02	0.02	0.02
Hg Removal Rate	%Hg Removed	95%	95%	99%	95%	99%	95%	99%
CO ₂ Removal Rate	% CO ₂ Removed	N/A	N/A	N/A	N/A	N/A	90%	90%
% Availability	% Time Avail.	93%	93%	93%	93%	93%	93%	93%

Table B-1: Integrated Gasification Combined Cycle⁹⁷

⁹⁷ Starting point data came from GTC members and was corroborated by recent NETL publications. These inputs were refined over 6 months during workshops, teleconferences, e-mailings, and special data review sessions. The 2025 data came from NETL estimates based on DOE goals. GTC members validated the 2025 data points.

Parameter	Units	Current Regulatory Framework - Snapshot	Current Regulatory Framework - Moderate Progression	Current Regulatory Framework - Advanced Progression	Multi- Pollutant Regulation - Moderate Progression	Multi- Pollutant Regulation - Advanced Progression	Multi- Pollutant Plus Carbon Regulation - Moderate Progression	Multi- Pollutant Plus Carbon Regulation - Advanced Progression
Plant Size	MW	550	550	550	550	550	550	550
Lead Time	Yr	4	4	4	4	4	4	4
Overnight Capital Cost in 2003	\$2003/kW	1200	1200	1200	1320	1320	2120	2120
Overnight Capital Cost in 2025	\$2003/kW	1200	1100	1100	1220	1220	2020	2020
Heat Rate in 2003	Btu/kW-Hr	8533	8533	8533	8597	8597	12548	12548
Efficiency (HHV) in 2003		40.0%	40.0%	40.0%	39.7%	39.7%	27.2%	27.2%
Heat Rate in 2025	Btu/kW-Hr	8533	7846	7262	7900	7308	11117	9980
Efficiency (HHV) in 2025		40.0%	43.5%	47.0%	43.2%	46.7%	30.7%	34.2%
Fixed O&M cost in 2003	\$2003/kW-yr	25.5	25.5	25.5	29.0	29.0	41.5	41.5
Fixed O&M cost in 2025	\$2003/kW-yr	25.5	24.5	23.0	28.0	26.5	40.5	39.0
Variable O&M (ex fuel) in 2003	\$2003 \$/MW-Hr	6.0	6.0	6.0	15.6	15.6	17.6	17.6
Variable O&M (ex fuel) in 2025	\$2003 \$/MW-Hr	6.0	5.6	5.4	15.2	15.0	17.2	17.0
SO ₂ Removal Rate	%SO ₂ Removed	98%	98%	98%	98%	98%	98%	98%
NO _x Emissions	lbNO _x / mmBtu	0.1	0.1	0.1	0.02	0.02	0.02	0.02
Hg Removal Rate	%Hg Removed	50%	50%	90%	70%	90%	70%	90%
CO ₂ Removal Rate	% CO ₂ Removed	N/A	N/A	N/A	N/A	N/A	90%	90%
% Availability	% Time Avail.	90%	90%	90%	90%	90%	90%	90%

Table B-2: Pulverized Coal-Supercritical⁹⁸

⁹⁸ Starting and ending point data came from the EPC members of GTC. These inputs were refined over 6 months during workshops, teleconferences, e-mailings, and special data review sessions.

Parameter	Units	Current Regulatory Framework - Snapshot	Current Regulatory Framework - Moderate Progression	Current Regulatory Framework - Advanced Progression	Multi-Pollutant Regulation - Moderate Progression	Multi-Pollutant Regulation - Advanced Progression
Plant Size	MW	180	180	180	180	180
Lead Time	Yr	2.0	2.0	2.0	2.0	2.0
Overnight Capital Cost in 2003	\$2003/kW	350	350	350	350	350
Overnight Capital Cost in 2025	\$2003/kW	350	315	315	315	315
Heat Rate in 2003	Btu/kW-Hr	10300	10300	10300	10300	10300
Efficiency (HHV) in 2003		33.1%	33.1%	33.1%	33.1%	33.1%
Heat Rate in 2025	Btu/kW-Hr	10300	10038	10038	10038	10038
Efficiency (HHV) in 2025		33.1%	34.0%	34.0%	34.0%	34.0%
Fixed O&M cost in 2003	\$2003/kW-yr	11.3	11.3	11.3	11.3	11.3
Fixed O&M cost in 2025	\$2003/kW-yr	11.3	8.0	8.0	8.0	8.0
Variable O&M (ex fuel) in 2003	\$2003 \$/MW-Hr	1.3	1.3	1.3	1.3	1.3
Variable O&M (ex fuel) in 2025	\$2003 \$/MW-Hr	1.3	1.1	1.1	1.1	1.1
SO ₂ Removal Rate	%SO ₂ Removed	100%	100%	100%	100%	100%
NO _x Emissions	lbNO _x /mmBtu	0.08	0.02	0.02	0.02	0.02
Hg Removal Rate	%Hg Removed	100%	100%	100%	100%	100%
CO ₂ Removal Rate	% CO ₂ Removed	N/A	N/A	N/A	N/A	N/A
% Availability	% Time Avail.	95%	95%	95%	95%	95%

Table B-3: 180 MW Natural Gas Simple Cycle Combustion Turbine⁹⁹

⁹⁹ Starting point data mainly came from the Gas Turbine World Handbook and was corroborated off-line by the turbine manufacturer members of GTC. The 2025 data came from off-line conversations with the turbine manufacturer members of GTC.

Parameter	Units	Current Regulatory Framework - Snapshot	Current Regulatory Framework - Moderate Progression	Current Regulatory Framework - Advanced Progression	Multi- Pollutant Regulation - Moderate Progression	Multi- Pollutant Regulation - Advanced Progression	Multi- Pollutant Plus Carbon Regulation - Moderate Progression	Multi- Pollutant Plus Carbon Regulation - Advanced Progression
Plant Size	MW	250	250	250	250	250	250	250
Lead Time	Yr	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Overnight Capital Cost in 2003	\$2003/kW	600	600	600	600	600	1200	1200
Overnight Capital Cost in 2025	\$2003/kW	600	550	550	550	550	1150	1150
Heat Rate in 2003	Btu/kW-Hr	6800	6800	6800	6800	6800	8709	8545
Efficiency (HHV) in 2003		50.2%	50.2%	50.2%	50.2%	50.2%	39.2%	39.9%
Heat Rate in 2025	Btu/kW-Hr	6800	6600	5688	6600	5688	8383	6965
Efficiency (HHV) in 2025		50.2%	51.7%	60.0%	51.7%	60.0%	40.7%	49.0%
Fixed O&M cost in 2003	\$2003/kW-yr	11.3	11.3	11.3	11.3	11.3	22.8	22.8
Fixed O&M cost in 2025	\$2003/kW-yr	11.3	8.0	8.0	8.0	8.0	19.5	19.5
Variable O&M (ex fuel) in 2003	\$2003 \$/ MW-Hr	1.3	1.3	1.3	1.3	1.3	2.6	2.6
Variable O&M (ex fuel) in 2025	\$2003 \$/ MW-Hr	1.3	1.1	1.1	1.1	1.1	2.4	2.4
SO ₂ Removal Rate	%SO ₂ Removed	100%	100%	100%	100%	100%	100%	100%
NO _x Emissions	lbNO _x / mmBtu	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Hg Removal Rate	%Hg Removed	100%	100%	100%	100%	100%	100%	100%
CO ₂ Removal Rate	% CO ₂ Removed	N/A	N/A	N/A	N/A	N/A	90%	90%
% Availability	% Time Avail.	95%	95%	95%	95%	95%	95%	95%

B-4: 250 MW Natural Gas Combined Cycle¹⁰⁰

¹⁰⁰ Starting point data mainly came from the Gas Turbine World Handbook and was corroborated off-line by the turbine manufacturer members of GTC. The 2025 data came from off-line conversations with the turbine manufacturer members of GTC.

Parameter	Units	Current Regulatory Framework - Snapshot	Current Regulatory Framework - Moderate	Current Regulatory Framework - Advanced	Multi- Pollutant Regulation - Moderate	Multi- Pollutant Regulation - Advanced	Multi- Pollutant Plus	Multi- Pollutant Plus
Plant Size	MW	550	550	550	550	550	550	550
Lead Time	Yr	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Overnight Capital Cost in 2003	\$2003/kW	550	550	550	550	550	1150	1150
Overnight Capital Cost in 2025	\$2003/kW	550	500	500	500	500	1100	1100
Heat Rate in 2003	Btu/kW-Hr	6700	6700	6700	6700	6700	8545	8545
Efficiency (HHV) in 2003		50.9%	50.9%	50.9%	50.9%	50.9%	39.9%	39.9%
Heat Rate in 2025	Btu/kW-Hr	6700	6300	5688	6300	5688	7905	6965
Efficiency (HHV) in 2025		50.9%	54.2%	60.0%	54.2%	60.0%	43.2%	49.0%
Fixed O&M cost in 2003	\$2003/kW-yr	11.3	11.3	11.3	11.3	11.3	22.8	22.8
Fixed O&M cost in 2025	\$2003/kW-yr	11.3	8.0	8.0	8.0	8.0	19.5	19.5
Variable O&M (ex fuel) in 2003	\$2003 \$/MW- Hr	1.3	1.3	1.3	1.3	1.3	2.6	2.6
Variable O&M (ex fuel) in 2025	\$2003 \$/MW- Hr	1.3	1.1	1.1	1.1	1.1	2.4	2.4
SO ₂ Removal Rate	%SO ₂ Removed	100%	100%	100%	100%	100%	100%	100%
NO _x Emissions	lbNO _x /mmBtu	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Hg Removal Rate	%Hg Removed	100%	100%	100%	100%	100%	100%	100%
CO ₂ Removal Rate	% CO ₂ Removed	N/A	N/A	N/A	N/A	N/A	90%	90%
% Availability	% Time Avail.	95%	95%	95%	95%	95%	95%	95%

Table B-5: 550 MW Natural Gas Combined Cycle¹⁰¹

¹⁰¹ Starting point data mainly came from the Gas Turbine World Handbook and were corroborated off-line by the turbine manufacturer members of GTC. The 2025 data came from off-line conversations with the turbine manufacturer members of GTC.

Parameter	Units	Distributed Generation Base - Updated	Distributed Generation Peak - Updated	Fuel Cell - Updated
Plant Size	MW	2	1	10
Lead Time	Yr	3	3	3
Overnight Capital Cost in 2003	\$2003/kW	800	959	2000
Heat Rate in 2003	Btu/kW-Hr	10500	10500	7500
Efficiency (HHV) in 2003		32.5%	32.5%	45.5%
Fixed O&M cost in 2003	\$2003/kW-yr	14.4	14.4	7.5
Variable O&M (ex fuel) in 2003	\$2003 \$/MW-Hr	6.4	6.4	21.3
SO ₂ Removal Rate	%SO ₂ Removed	100%	100%	100%
NO _x Emissions	lbNO _x /mmBtu	0.08	0.08	0.00
Hg Removal Rate	%Hg Removed	100%	100%	100%
CO ₂ Removal Rate	% CO ₂ Removed	N/A	N/A	N/A
% Availability	% Time Avail.	90%	90%	93%

Table B-6: Distributed Generation and Fuel Cell Input Data¹⁰²

¹⁰² Distributed Generation inputs from Capstone Turbine Corporation Presentation; *Advanced Reciprocating Engines Systems (ARES) Program*.
Fuel Cell inputs from the National Power Technologies Data Book and Renewable Energy Technology Characterizations.

Appendix C: Process Details

C.1. Why a Scenario Analysis?

Scenarios are descriptions of alternative futures from which analyses can be performed. The concept of scenario analyses was first designed by the military to help plan operations, often called “war games.” Now, scenario analyses are regularly used by military and civilian organizations around the world for training and planning purposes.

Decision makers use scenario analysis to give systematic consideration to the uncertainties inherent in planning for the future. For example, portfolio managers often perform macro- and micro-economic scenario analyses to assess how their assets might perform considering their different risk profiles. By their nature, scenario analyses are not perfect forecasts or predictors of the future. Instead, they provide a well-established way to consider the impacts of alternative possibilities.

The major benefits of scenario analyses are the following:

- Closely controls background, independent, and dependent variables;
- Keeps the framework coherent and simple for focusing on critical factors;
- Provides a “testing ground” for policy decisions;
- Explores and explains uncharted territory;

- Provides accessible insight on technology, policy, and economic impacts, both positive and negative;
- Identifies strategies that perform adequately over a range of conditions as well as those that do very well under some conditions, but fail under others;
- Builds group consensus;
- Expands perceptions and horizons;
- Promotes communication and learning; and
- Legitimizes actions.

C.2. Data Gathering/Analyzing

The data-gathering step involved a close examination of proposed environmental regulations, technology assessments, potential natural gas futures, and policy incentives. This iterative step involved literature reviews, phone interviews, e-mailings, teleconferences, and data review meetings to formulate the best assumptions and data for the study. For the assumptions and data regarding future environmental regulatory scenarios, the study team researched proposed legislation and regulation at the Federal level. The team also qualitatively looked at the state-level regulatory trends in emission reductions.

Because the majority of the study’s participants were fossil power generation experts, the technology data used for modeling relied more

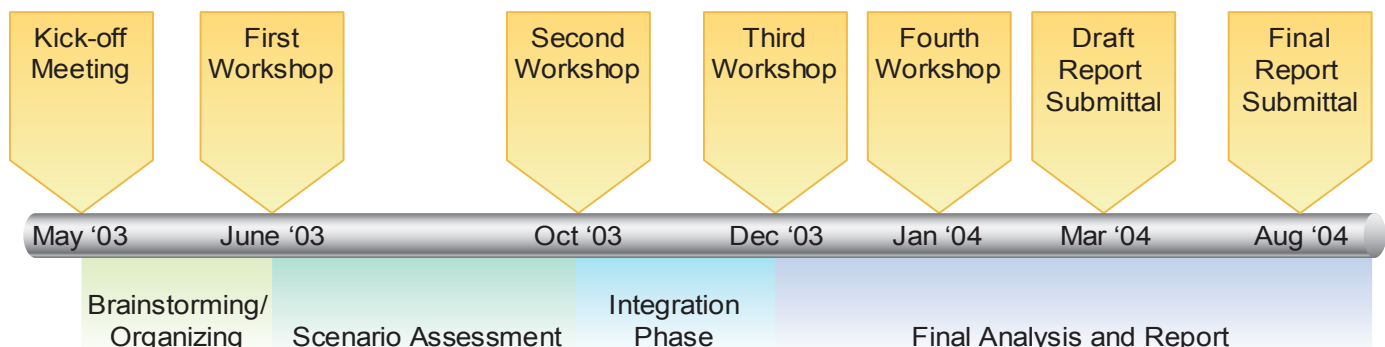


Figure C-1: Study Timeline

heavily on their input than from literature reviews. Data and assumptions for distributed generation, fuel cell, and all non-fossil technologies, on the other hand, were unchanged from EIA's original datasets.

During the course of the data-gathering step, the study team strictly adhered to the GTC's antitrust policy. The anti-trust policy is stated as follows:

It is the policy of the Council to comply with all laws applicable to its operations. Therefore, it is the intent and expectation of the Board of Directors that the officers, directors and staff of the Council, as well as all members and any of their employees who participate in Council affairs, will familiarize themselves with the antitrust and related laws and this statement of policy and that they will comply with the requirements thereof.

The study team, recognizing this sensitive issue, took many steps to ensure the anonymity of participant's information. For example, the study team masked cost and efficiency estimates, analyzed the data, and then anonymously displayed the low, high, and average values to the entire group. The group then agreed to whether the data appeared reasonable for modeling without knowing who provided the data.

Throughout the study, the participants avoided anti-trust issues involved with discussing IGCC market penetration strategies. Market strategy suggestions were based solely on independent research and derived from accepted market characterization. In structuring the market analysis approach, the study team used two well-regarded frameworks for analyzing and assessing the market place: Porter's 5 Forces and the SWOT analysis. Both of these frameworks are extensively taught in business schools and applied systematically throughout industries. Harvard Business School's Michael Porter developed

Porter's 5 Forces, which assesses the attractiveness of an industry. The SWOT analysis takes the 5 Forces analysis a level further by examining the positioning within the industry. From the SWOT analysis, the study and its participants generated five different market penetration options.

The assumptions and data for the natural gas price scenarios came primarily from two published sources: the EIA's AEO2004 and the NPC's *Balancing Natural Gas Policy*.¹⁰³ The AEO2004 natural gas price track served as the base natural gas scenario for the study. A combination of the natural gas future's curve and the NPC's high reactive natural gas price case represented the high natural gas price scenario in the study.

For the policy incentive scenario, the study simulated the impact of proposed incentives in the Energy Conference Committee Version of the Energy Policy Act of 2003 (H.R. 6). The analysis used inputs that closely resemble the generation-based incentives.

C.3. Modeling

NEMS does not currently allow the introduction of new technologies or plant reconfigurations, such as repowering and refueling, beyond a pre-programmed validated set. To deal with this, the study developed parameters for some of the technology "slots" to represent a range of

applicable technologies. They also developed a separate Power Pricing Model to investigate the economics of specific IGCC-relevant technology improvements and reconfigurations.

Capacity additions: The model compares projected demand with available (existing less retirements) capacity to determine the amount of additional capacity that is required. Before building plants,

How NEMS Works

EIA describes the NEMS process as follows:

The model achieves a supply-and-demand balance in the end-use demand regions, defined as the nine Census Divisions, by solving for the prices of each energy type, so that the quantities producers are willing to supply equal the quantities consumers wish to consume. The system reflects market economics, industry structure, and energy policies and regulations that influence market behavior.

US. Energy Information Administration, *Directory of EIA Models 2002*, DOE/EIA 0293 (2002/11), p. 1

NEMS finds equilibrium prices by iteration. For example, if residential demand for electricity were projected to exceed the supply in a region during a certain year, NEMS would raise its assumed price of electricity in the residential sector of that region for that period. It would then re-run its forecasts, generating direct and indirect impacts to energy, economic, and environmental outcomes, and would then check to see if electricity supply and demand were in agreement. NEMS repeats this process of changing prices, re-forecasting, and evaluating until all supply-demand balances and constraints are met, within set tolerances.

¹⁰³ Shackouls, B.S.

NEMS first considers Load Management (LM) strategies that could be employed to reduce demand and hence need for new capacity. After netting out LM, NEMS fills remaining capacity slots on the basis of minimizing the present value of after-tax cash flows. All analysis is done within NERC regions based on “look ahead” electricity prices, demand and fuel costs. A “threshold amount” of capacity must be available within the region; this is usually 30 percent for regulated utilities and smaller for deregulated plants. That is, there must be 300 MW of capacity need within a region before the plant will be built. It is assumed that the remainder of capacity will be available for inter-regional trades. Thus, the model trades off capital and fuel costs through the discounted cash flow methodology.

Dispatch of electricity is based on minimizing the cost of electricity, particularly minimizing variable cost. An increase in fuel cost means that less electricity will be dispatched from plants using that fuel. In general, coal plants dispatch first and gas plants dispatch last.

There is a considerable amount of “real world” support for this position: Due to low capital costs and the anticipation of low future prices, much of the new capacity in the past 15 years has been gas-fired. Today, most of these gas plants sit idle.

In the literature, there are a number of studies in which other potential limitations of NEMS modeling are identified. Many of these studies disagree with the data input assumptions, or point out modeling features that could be added to illuminate policies that are not directly relevant to IGCC market penetration.¹⁰⁴ In places that such concerns could significantly affect the market penetration analysis, this study performed sensitivity analyses.

How the Study Validated Model Runs

Convergence:

As a model's forecast approaches a valid solution (with supply equal to demand), its outputs converge—they stop changing from cycle to cycle as the model refines its forecast. EIA aggregates convergence of over 700 outputs into an index ranging from 0.0 (bad) to 4.0 (good), much like a grade point average (GPA). EIA reports results only when the GPA is at least 2.7. The results in this report attained GPAs of 3.0 or greater.

Comparability:

Some scenarios in this study were similar to published EIA NEMS scenarios. The current and published results were compared for key outputs, including:

- Electric generation capacity additions by type
- Total capacity additions
- Natural gas prices
- Generation retirements by type

Any differences above 5 percent were checked for agreement, in direction and size, with differences between the models' assumptions and input parameters.

Indirect results:

Indirect results—those derived from combinations of model outputs—can reveal systematic modeling errors. The team compared two key indirect results against historical trends and ranges to confirm validity:

- Imputed aggregate heat rates for coal and natural gas
- Natural-gas demand/price ratio

Event timing:

Most scenarios had discrete regulatory changes occurring in specific years. Outputs that were expected to be sensitive to these changes were plotted vs. time. The study identified significant changes in the plots' slopes, and confirmed that the timing coincided with the regulatory changes.

Expected results:

The study generated a list of expected output differences for pairs of scenarios that differed in only one dimension (such as technological assumptions, regulatory assumptions, or natural gas price assumptions). Expectations included differences in:

- Electricity, natural gas, and coal demand and prices;
- Cumulative additions, by technology and fuel source;
- Cumulative retirements, by technology and fuel source;
- Cross elasticity effects of electricity, natural gas, and coal demand and prices; and
- Total U.S. emissions, compared with each emissions for the electricity sector.

The model results were examined to confirm agreement, in direction and order of magnitude, with the expectations. Any unexpected results were flagged for further investigation.

Unexpected results:

The study analyzed unexpected results to identify the root causes of the differences between expectations and outcomes. After identifying the parameters or assumptions responsible for the differences, the team consulted expert sources for verification or correction.

If the sources suggested changes to the parameters or assumptions, the team examined and, if warranted, adopted the changes as valid feedback. If the sources believed that the parameters or assumptions were valid, then the unexpected results were highlighted as potential insights and marked for further analysis.

¹⁰⁴ For example, the Pew Center for Climate Change [2001] criticized NEMS for not permitting retrofits; as of 2003, there were case models that permitted extensive retrofitting.

As part of the quality assurance procedures for the project, the study followed a predefined, step-by-step procedure to confirm that the model was properly configured and operating as expected. Six criteria questions were applied to the model outputs:

1. Does the model find a mathematically consistent forecast?
2. Do the model results agree with comparable results published by the EIA?
3. Are indirect results consistent with historical trends?
4. Are time-dependent events reflected correctly in the output?
5. Do differences between scenario results meet expectations?
6. Can unexpected results be traced to a cause?

If all of the criteria questions were answered positively, the results were considered valid. The root cause of any unmet criterion was investigated. Any errors were corrected, and any unexpected results remaining were investigated as potential insights.

The study's general approach was to adjust the inputs to the baseline NEMS model to reflect different assumptions about environmental constraints, technology progression, natural gas prices, and policy incentives. The resulting IGCC capacity additions were compared for insights about the effects of the assumptions.

The Power Pricing Model was used to investigate several IGCC market penetration options such as retrofitting of existing coal-fired plants and the refueling of NGCC plants with IGCC units because these options are not fully modeled in the early 2004 versions of NEMS.

Several other factors that could be relevant to IGCC market penetration are difficult to quantify, such as benefits from reduced climate change impacts, increased energy security, increased use of local coal resources, or increased local employment. The study considered the potential impacts of these factors in a qualitative analysis, using Public Utilities Commission (PUC) and other regulatory documents, analyses by government and non-profit organizations, grant requests, local press articles, and other relevant documents to understand the non-quantified factors that could influence decisions on IGCC investments.

Appendix D: Modeling Results

This appendix provides additional charts for the scenarios modeled. The information within these charts gives further context to the scenarios. Included in this appendix are IGCC additions in both gigawatts and as a percent of total projected additions; coal retirements and total retirements;

cumulative capacity additions of electricity generation for advanced technology and high natural gas prices; prices, demand, and capacity factors for coal, natural gas, and electricity; and emission levels of SO₂, NO_x, mercury (Hg), and carbon for all the scenarios modeled.

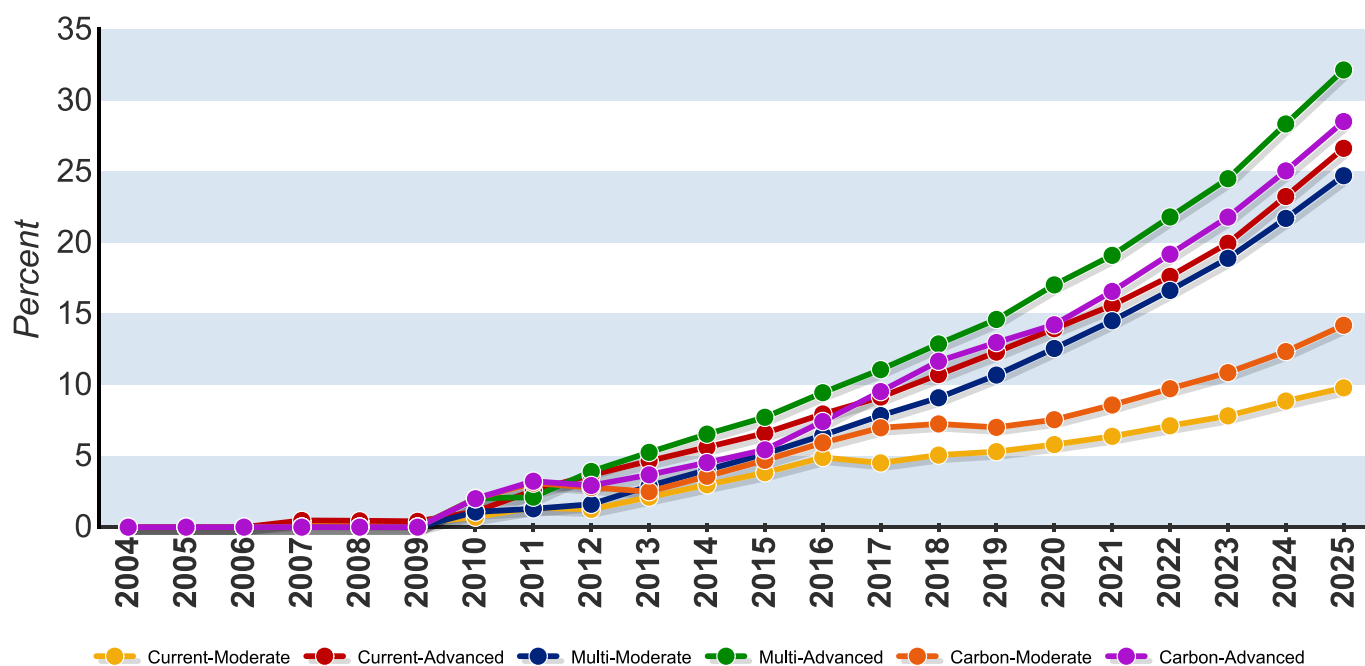
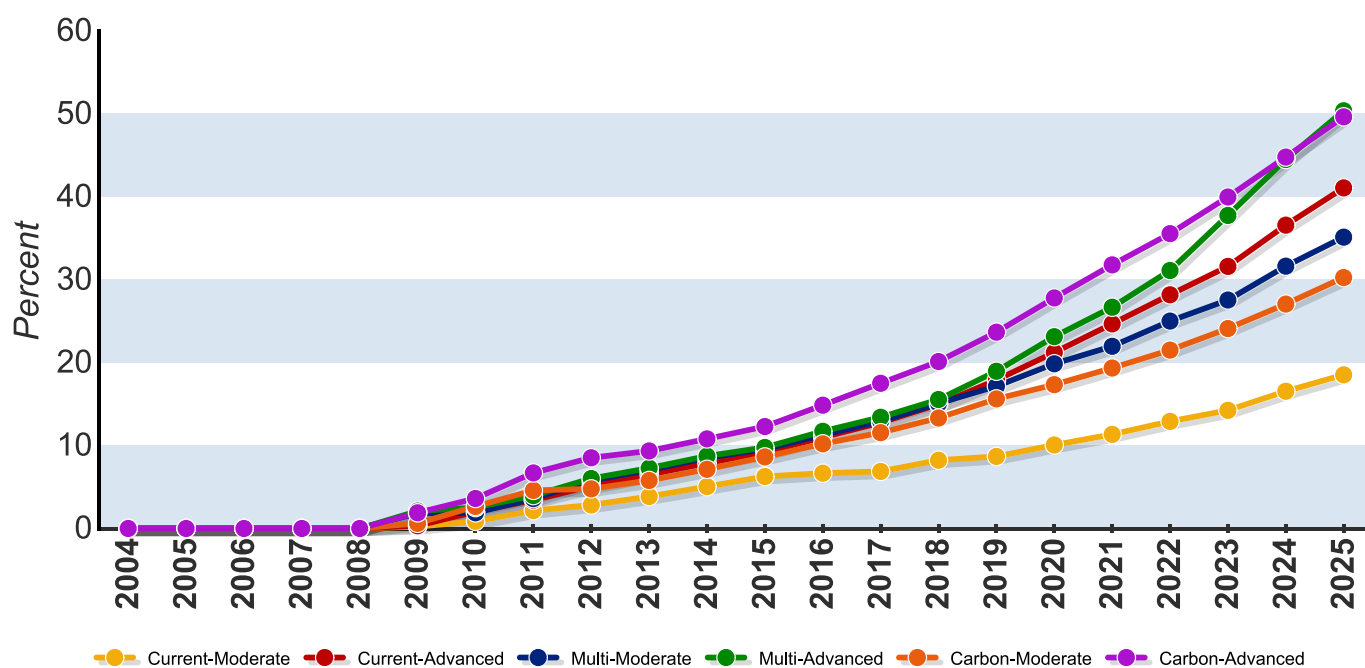
Figure D-1: IGCC as a Percent of Total Additions-Base NG Prices¹⁰⁵

Figure D-2: IGCC as a Percent of Total Additions-High NG Prices

¹⁰⁵Current – Current Regulatory Framework
 Multi – Multi-Pollutant Regulation
 Carbon – Multi-Pollutant Plus Carbon Regulation
 Moderate – Moderate Technology Progression
 Advanced – Advanced Technology Progression

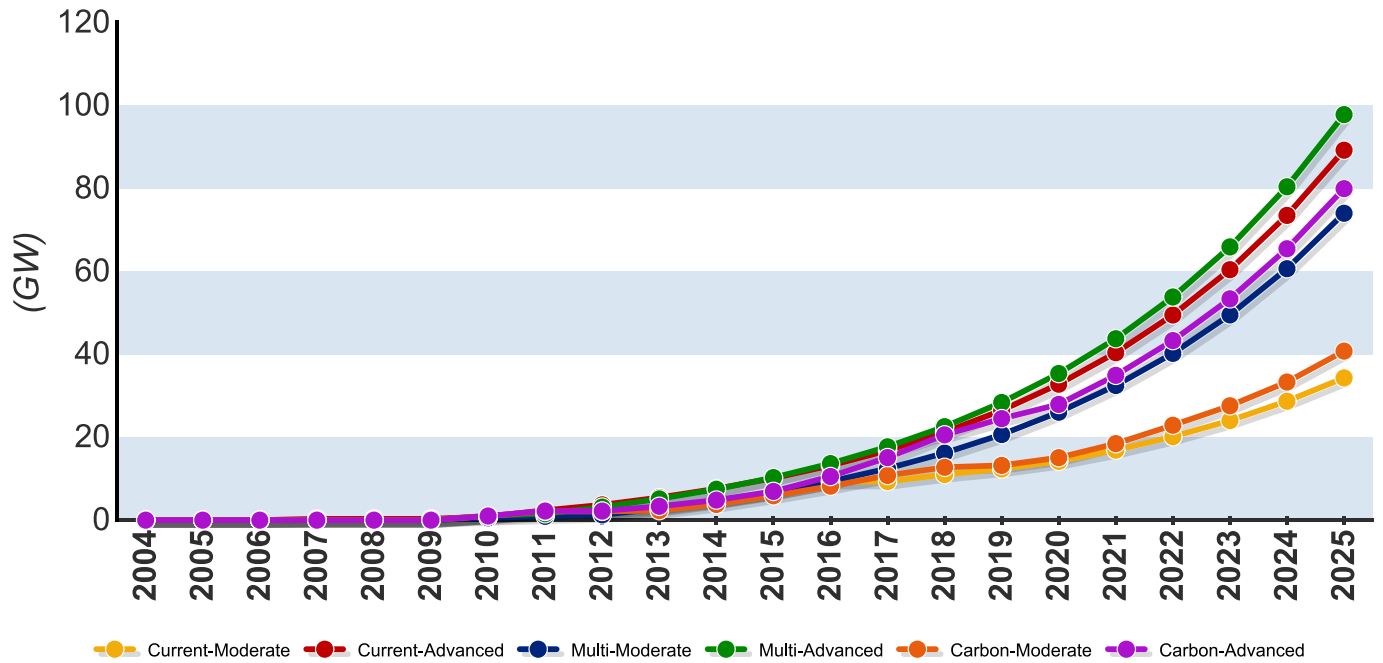


Figure D-3: IGCC Additions-Base NG Prices

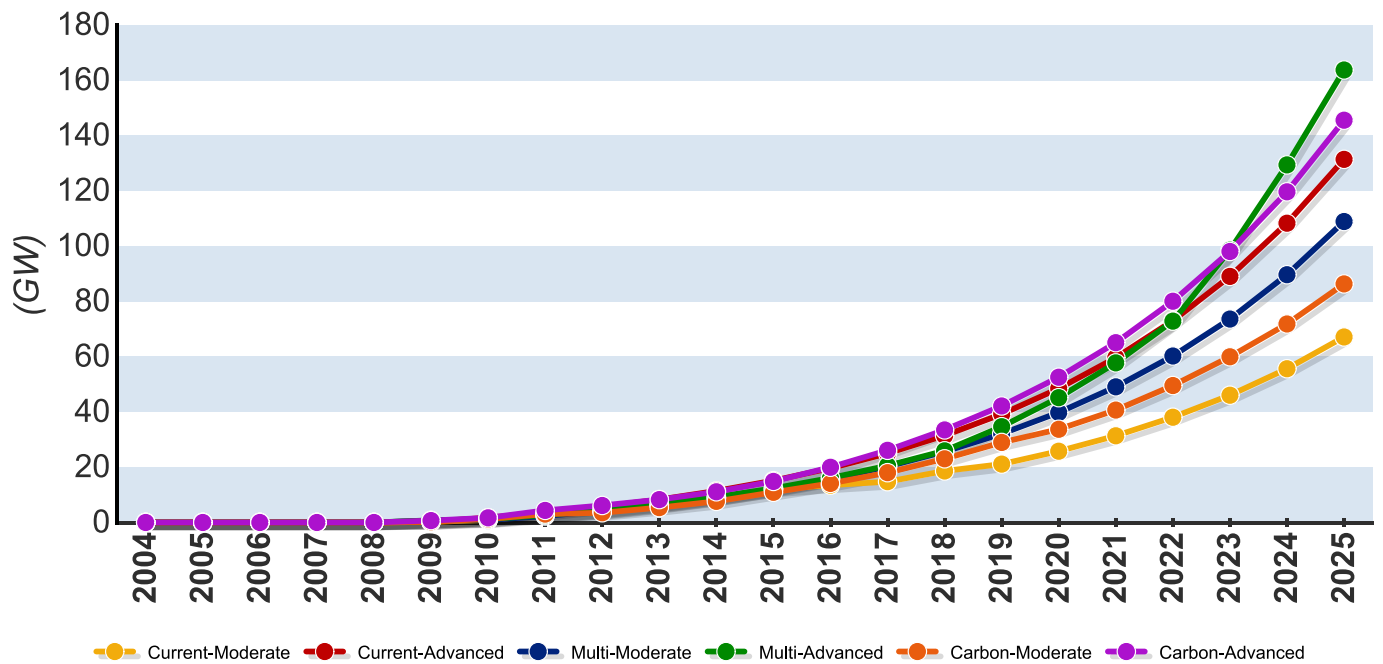


Figure D-4: IGCC Additions-High NG Prices

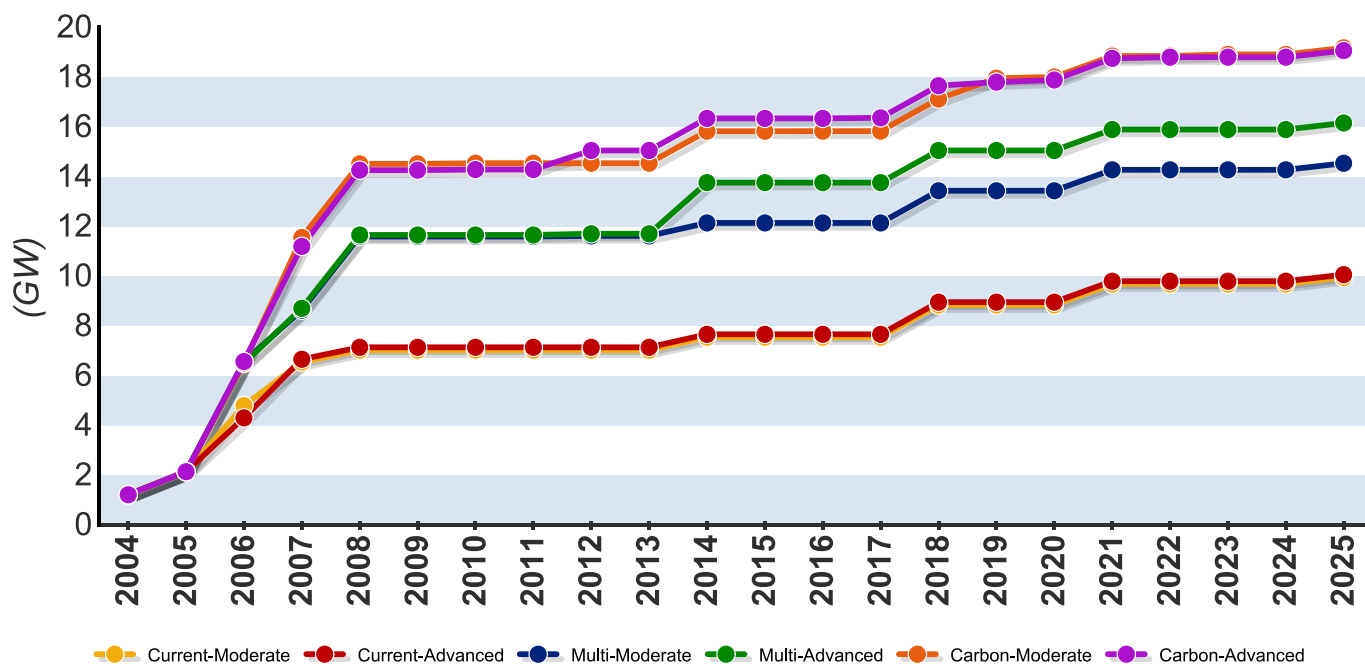


Figure D-5: Coal Retirements-Base NG Prices

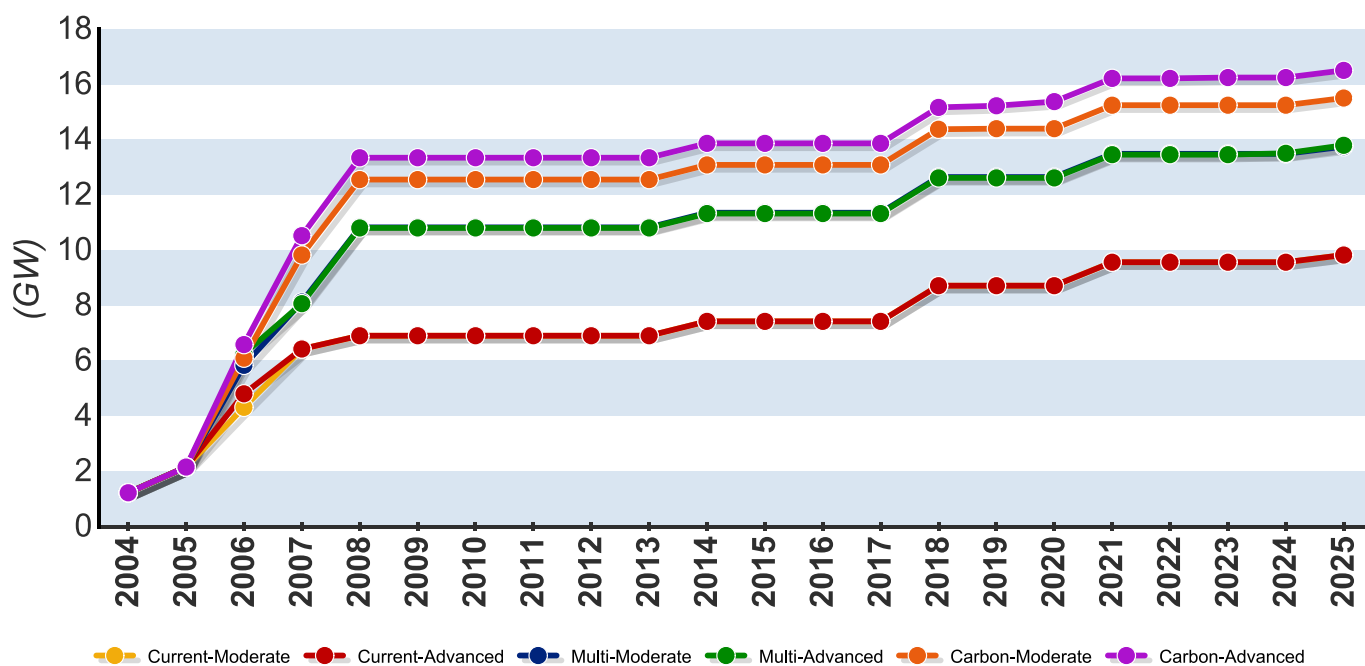


Figure D-6: Coal Retirements-High NG Prices

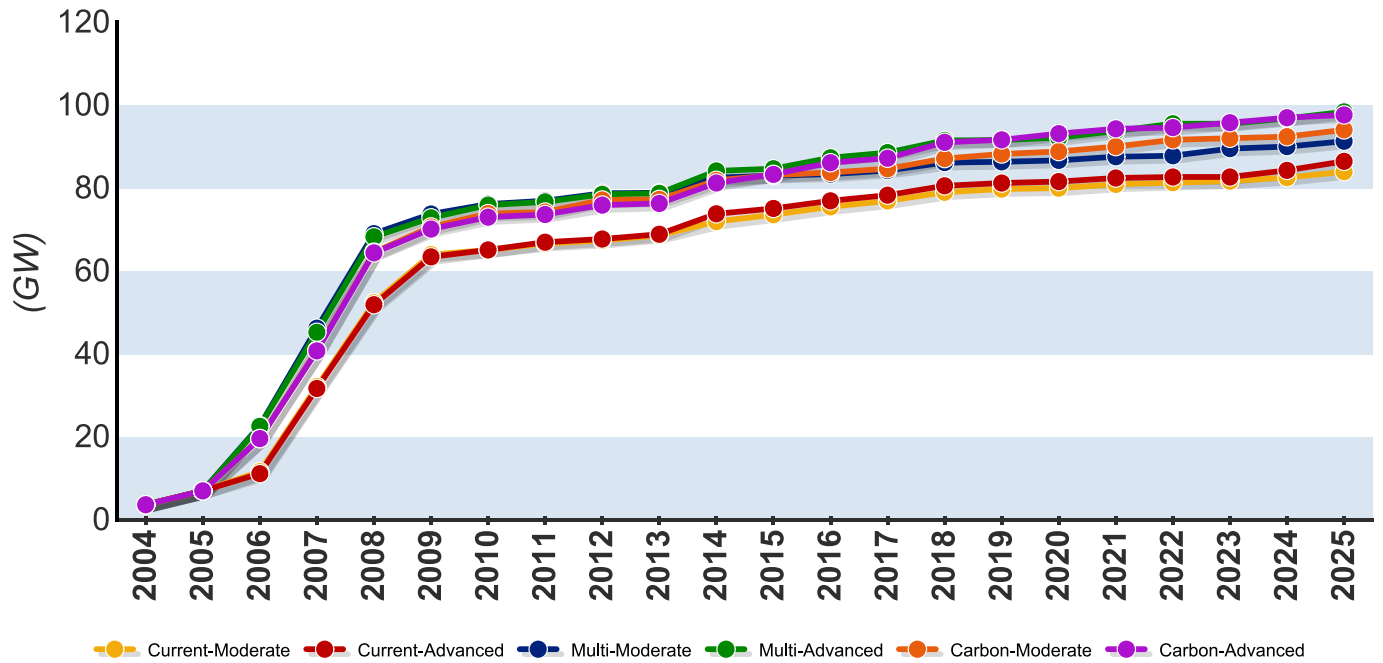


Figure D-7: Total Retirements-Base NG Prices

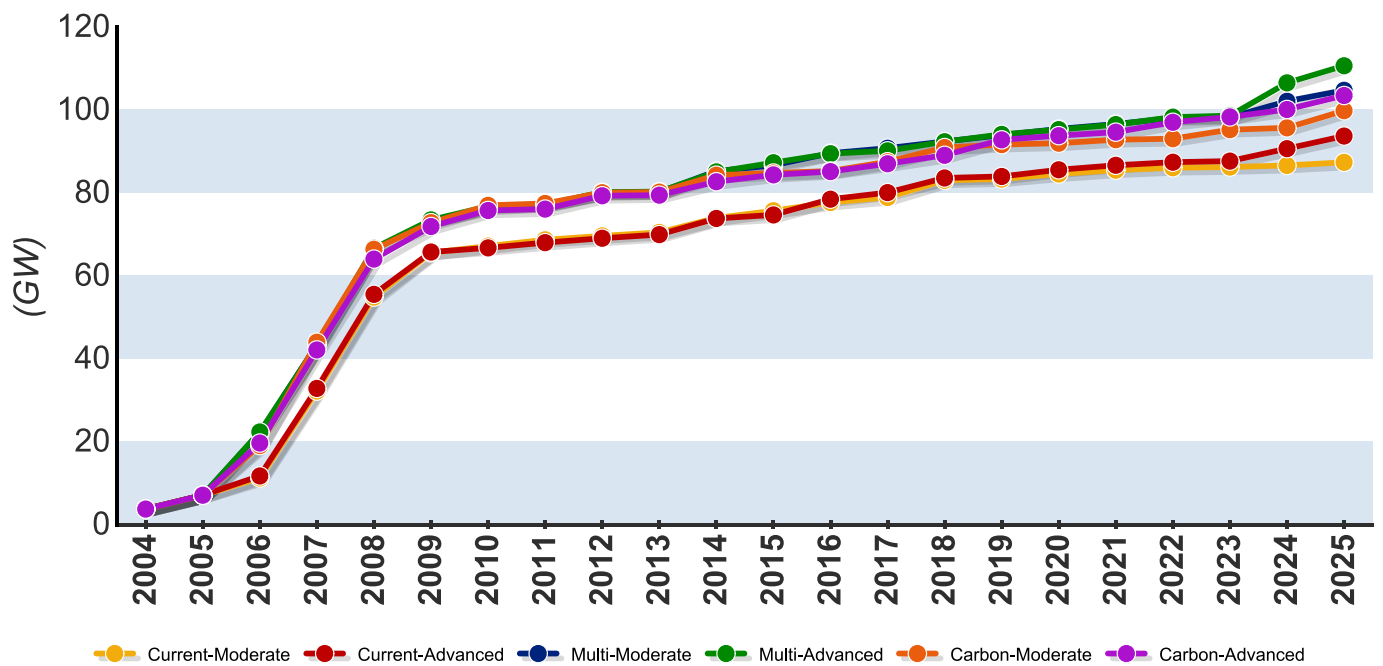


Figure D-8: Total Retirements-High NG Prices

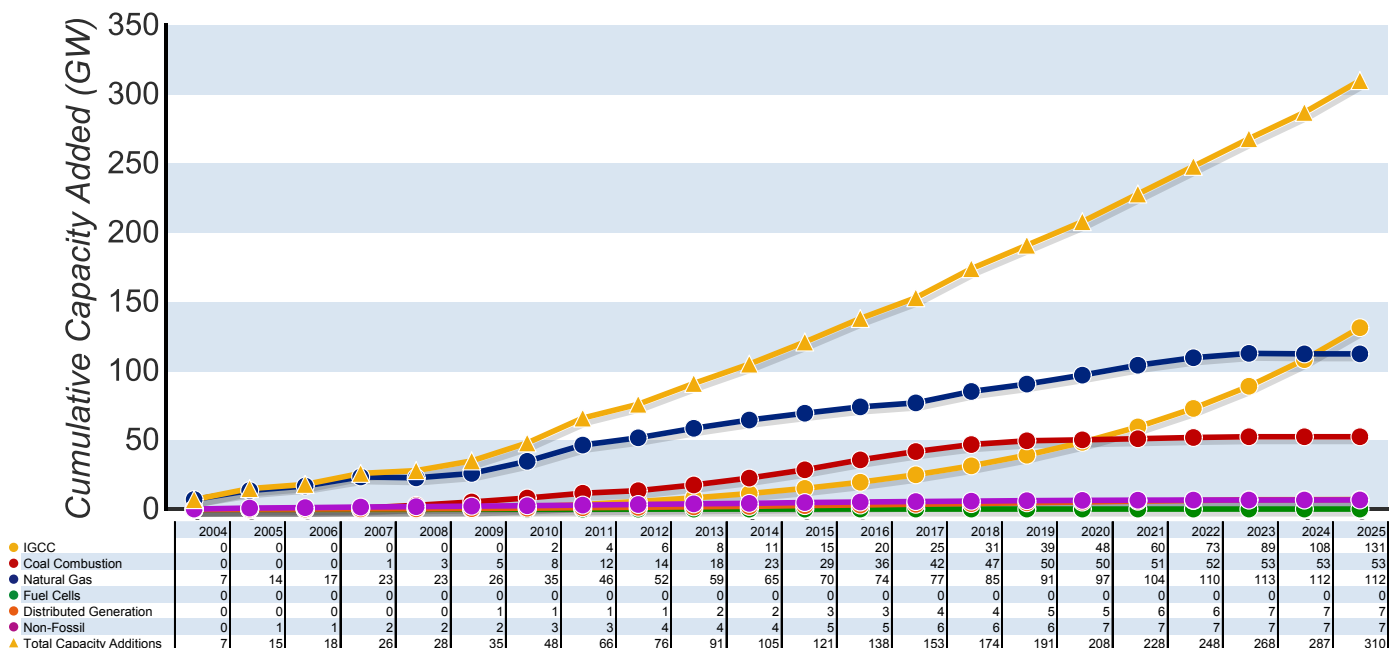


Figure D-9: Cumulative Additions of Electricity Generation Capacity, 2004–2025 Under Current Regulatory Framework, Advanced Technology and High NG Prices

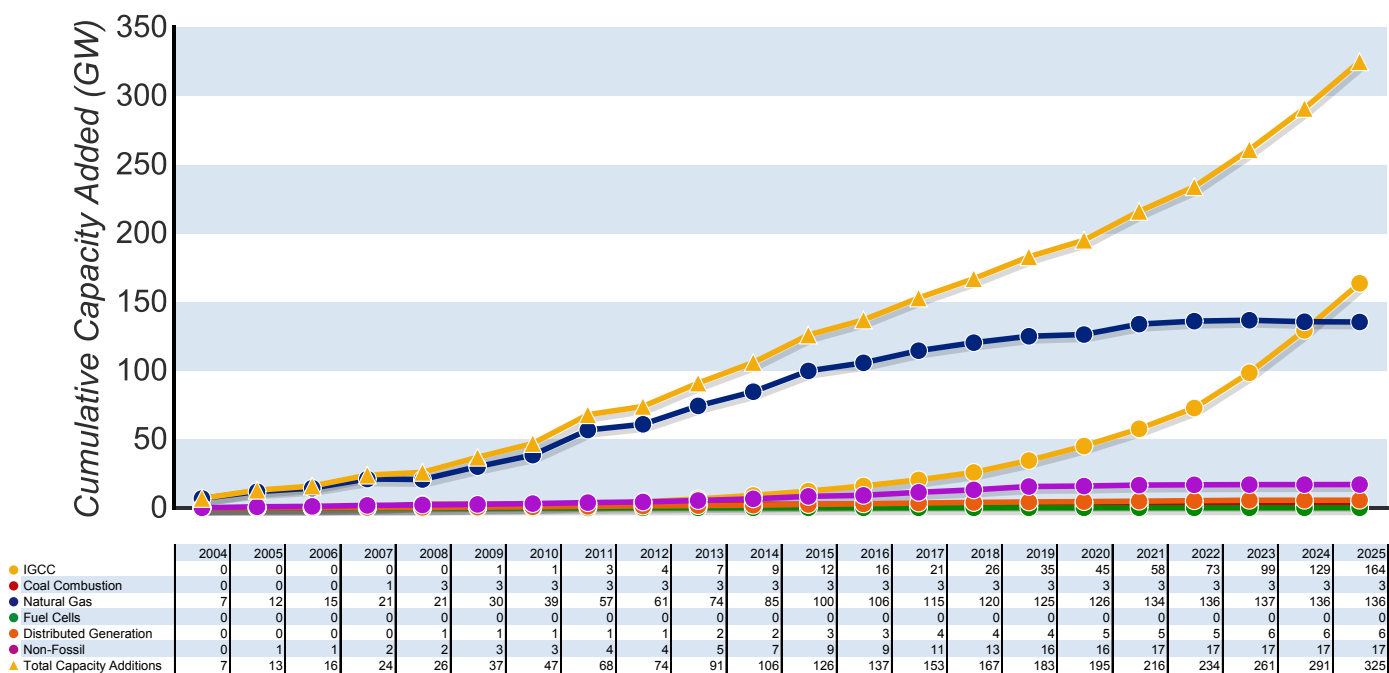


Figure D-10: Cumulative Additions of Electricity Generation Capacity, 2004–2025 Under Multi-Pollutant Regulation, Advanced Technology and High NG Prices

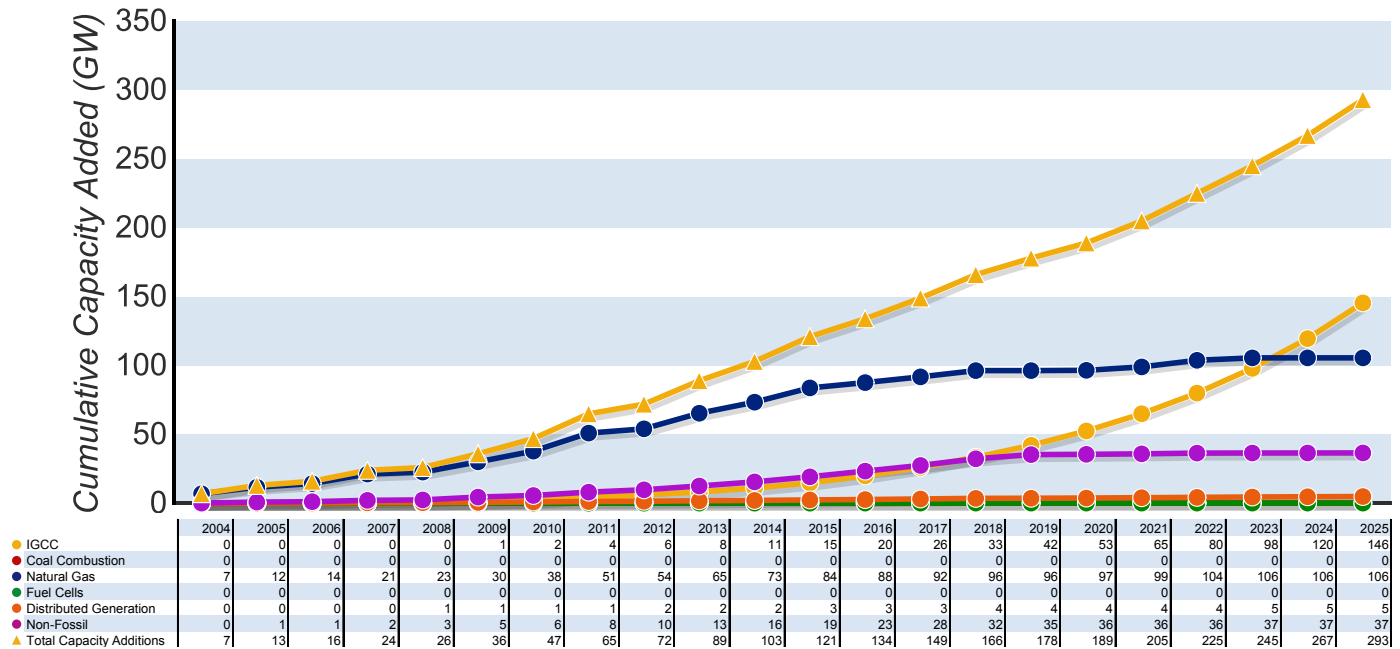


Figure D-11: Cumulative Additions of Electricity Generation Capacity, 2004–2025
Under Multi-Pollutant Plus Carbon Regulation, Advanced Technology and High NG Prices

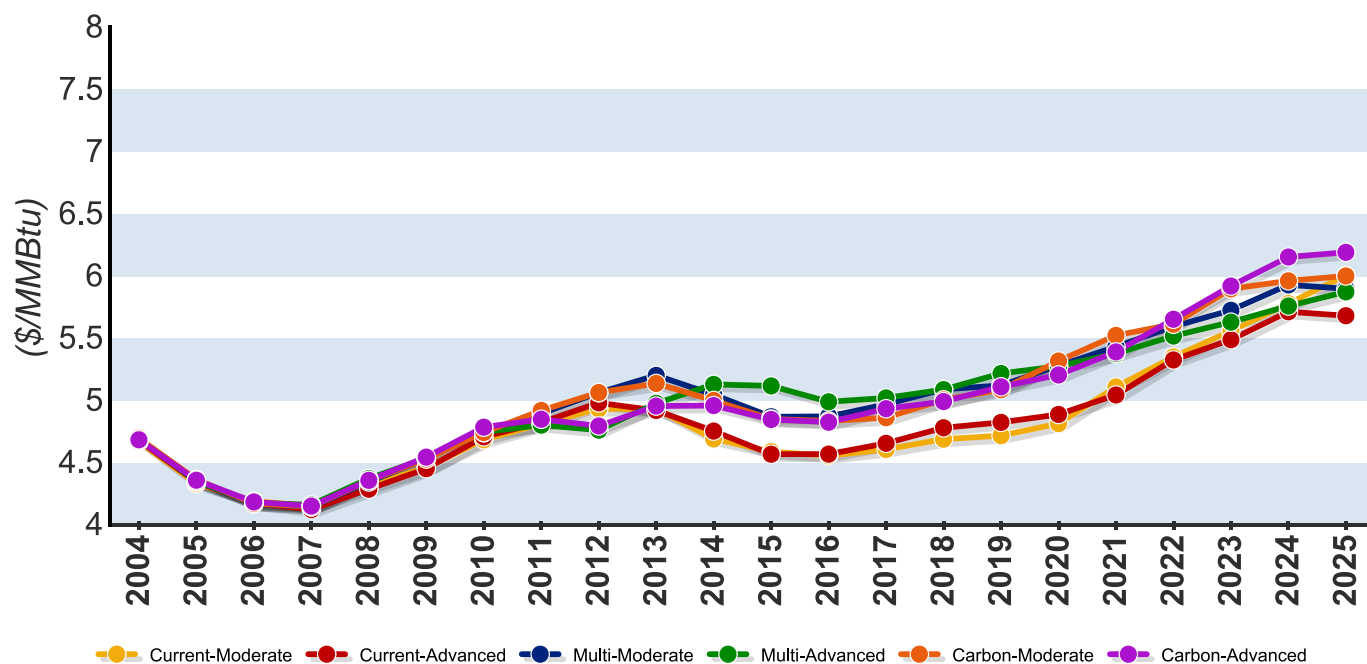


Figure D-12: Natural Gas Prices-Base NG Prices

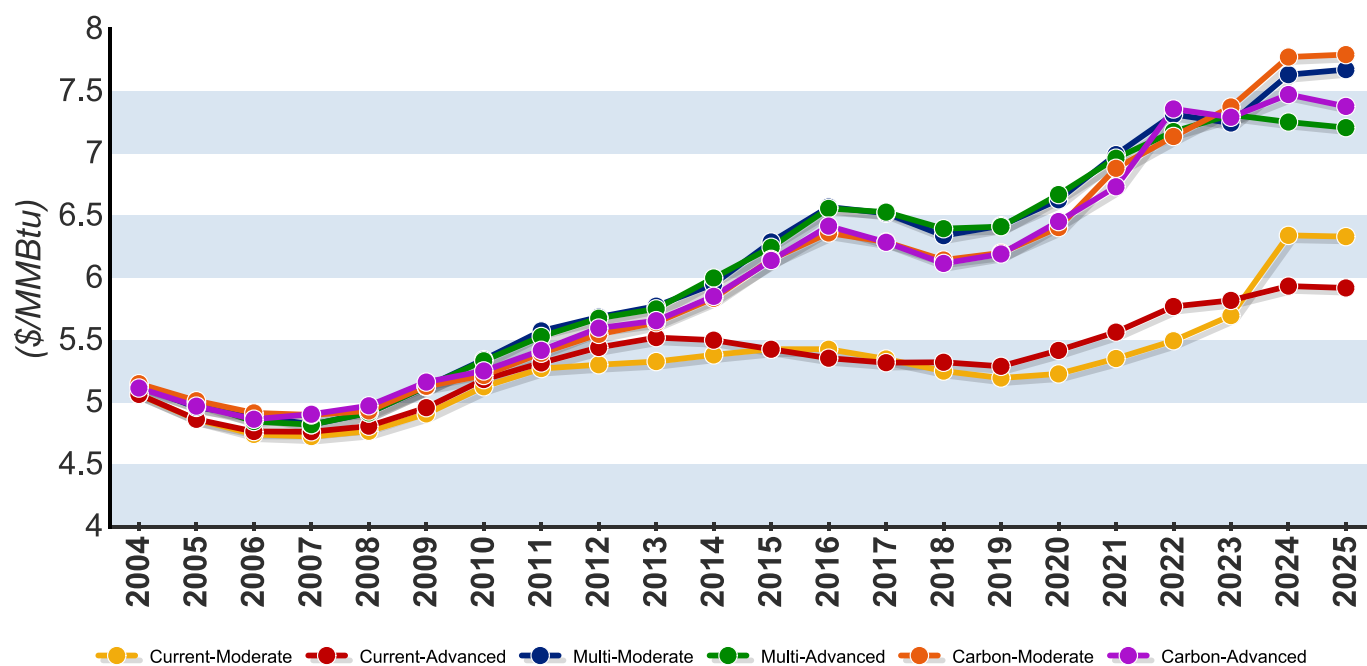


Figure D-13: Natural Gas Prices-High NG Prices

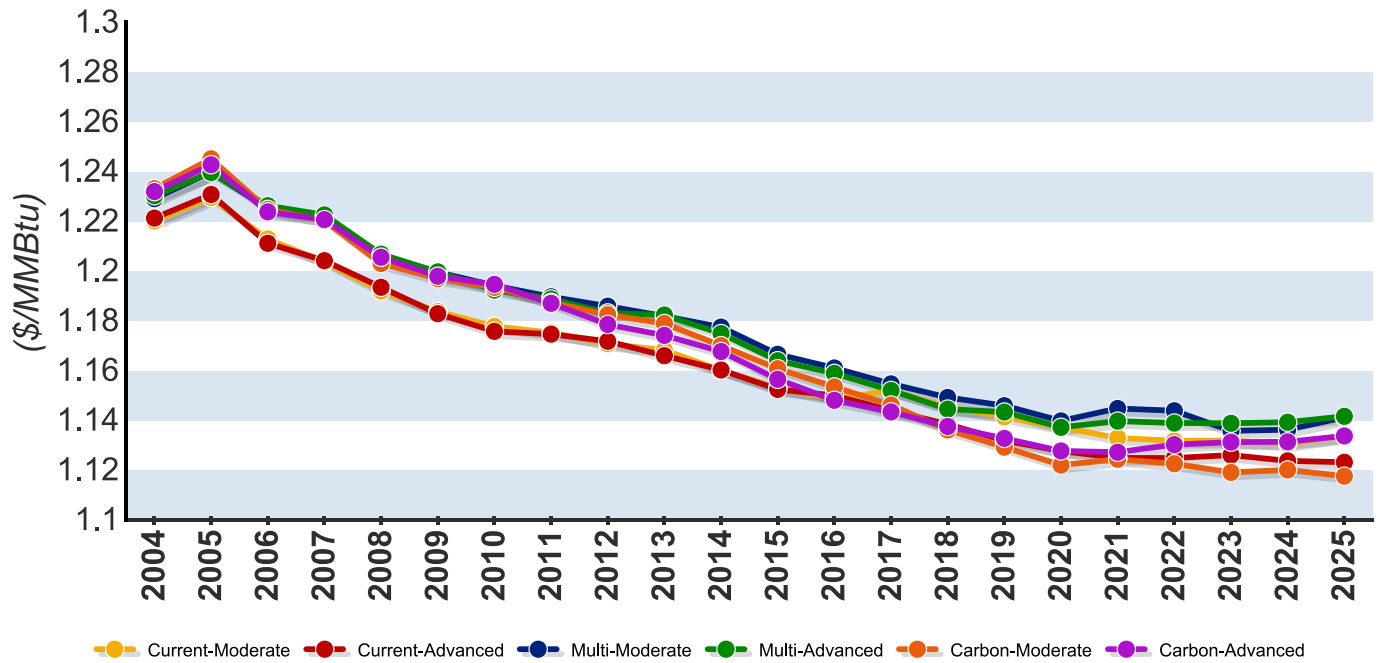


Figure D-14: Coal Prices-Base NG Prices

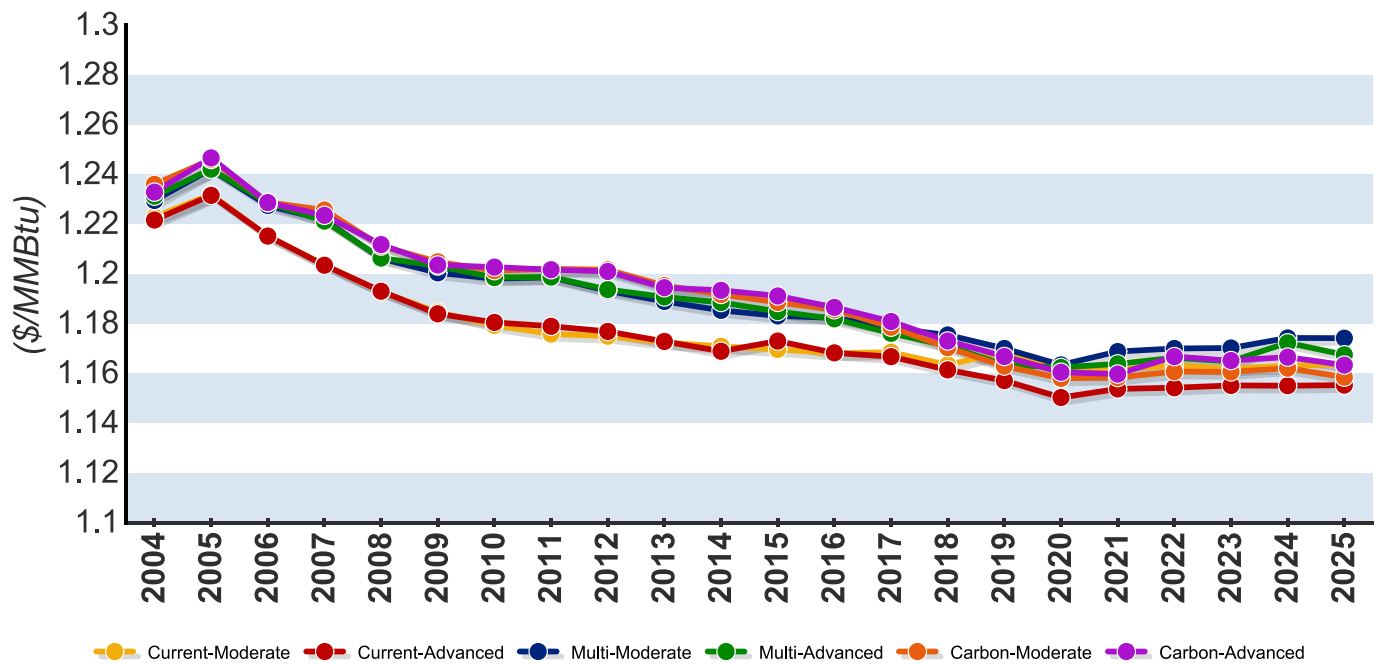


Figure D-15: Coal Prices-High NG Prices

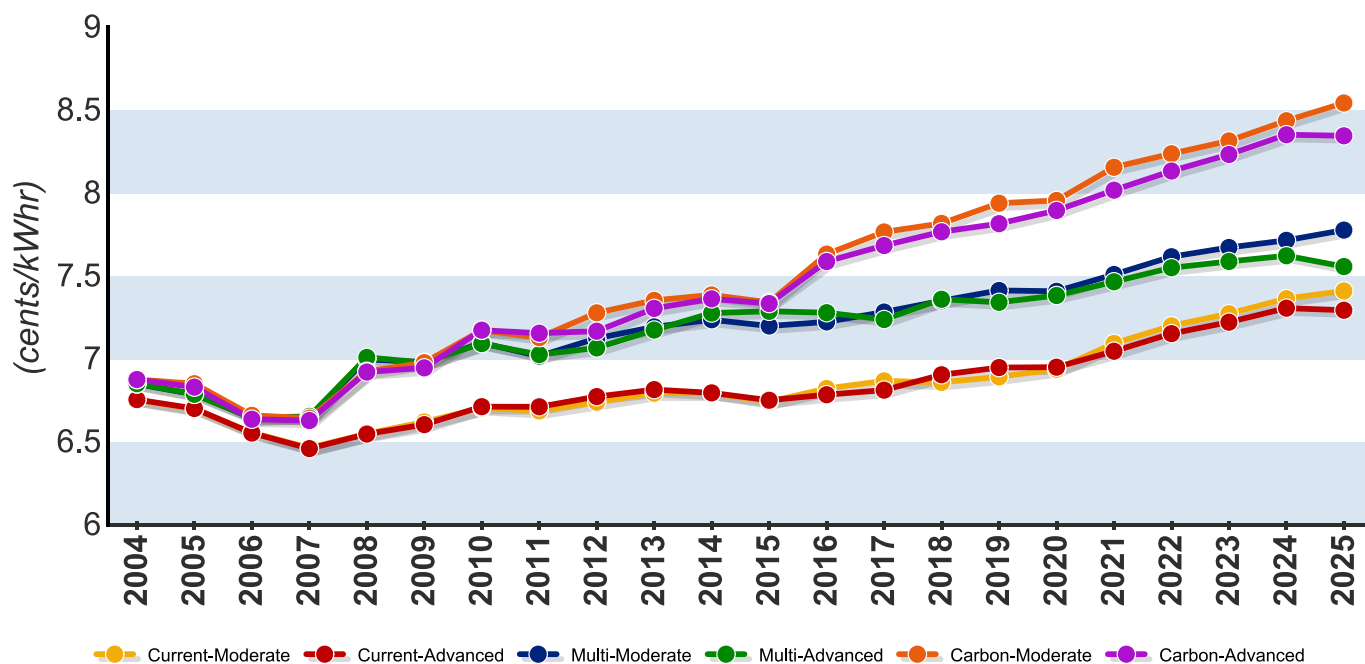


Figure D-16: Cost of Electricity-Base NG Prices

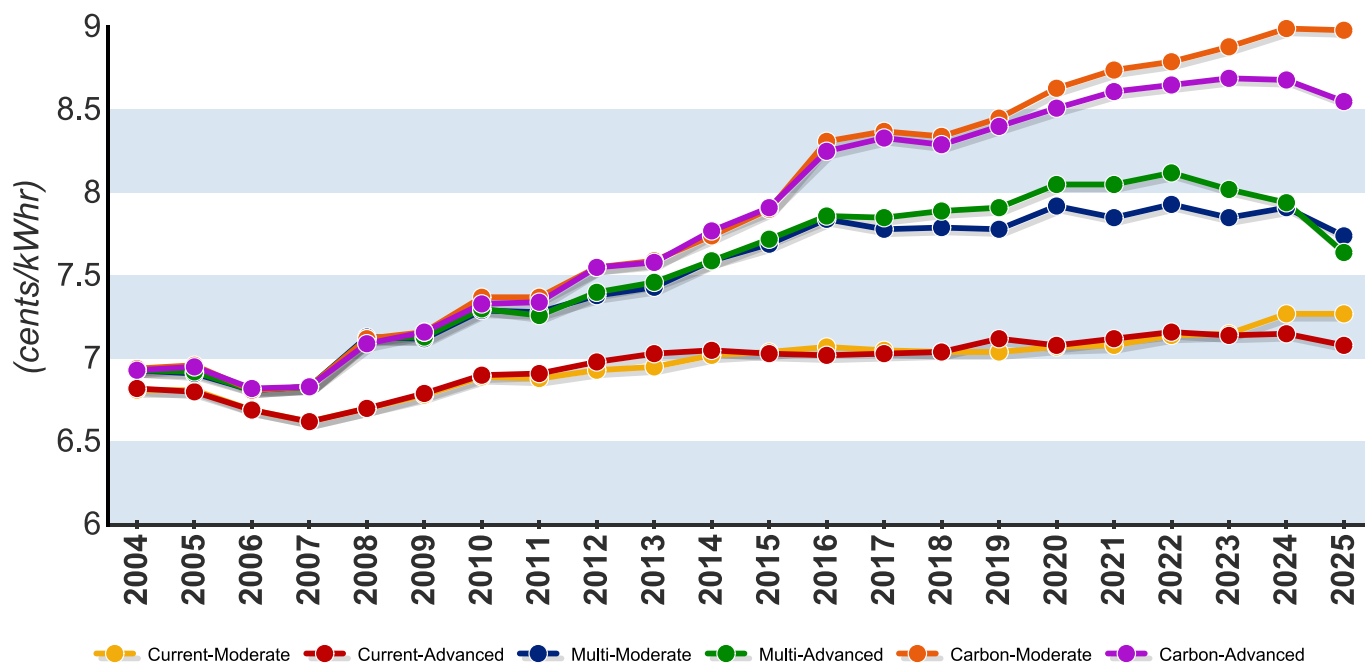


Figure D-17: Cost of Electricity-High NG Prices

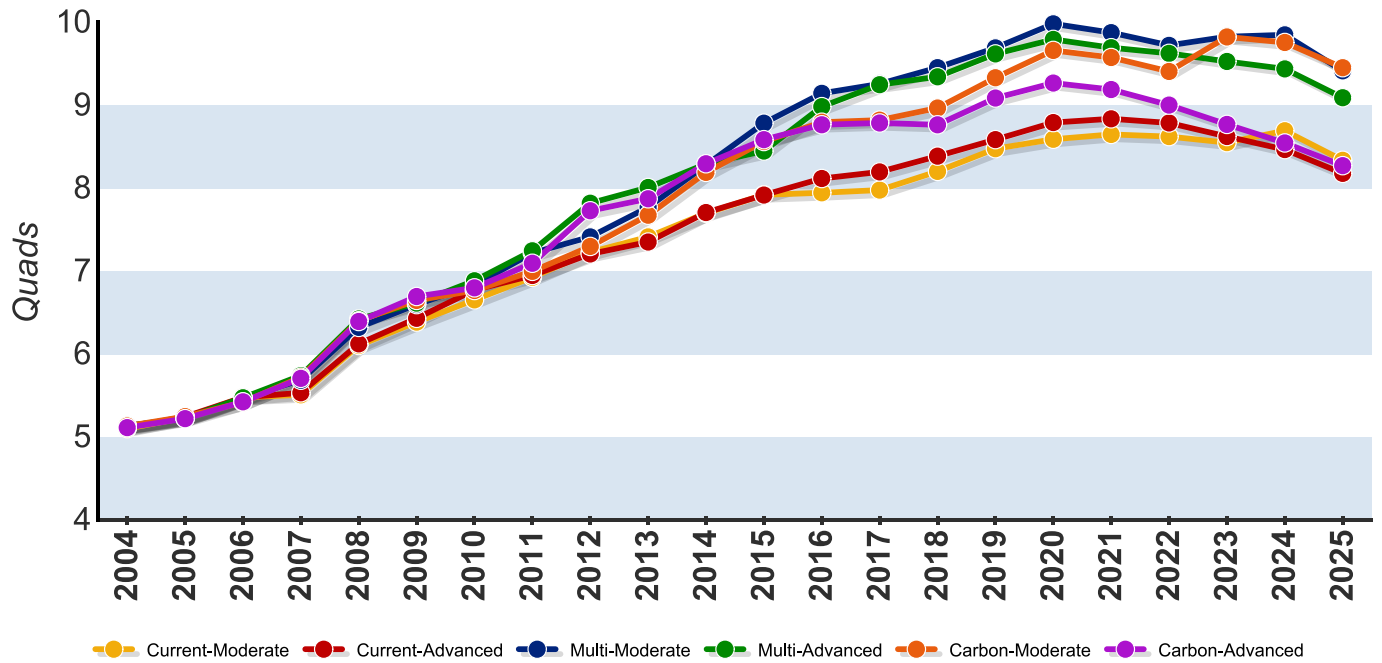


Figure D-18: Natural Gas Demand-Base NG Prices

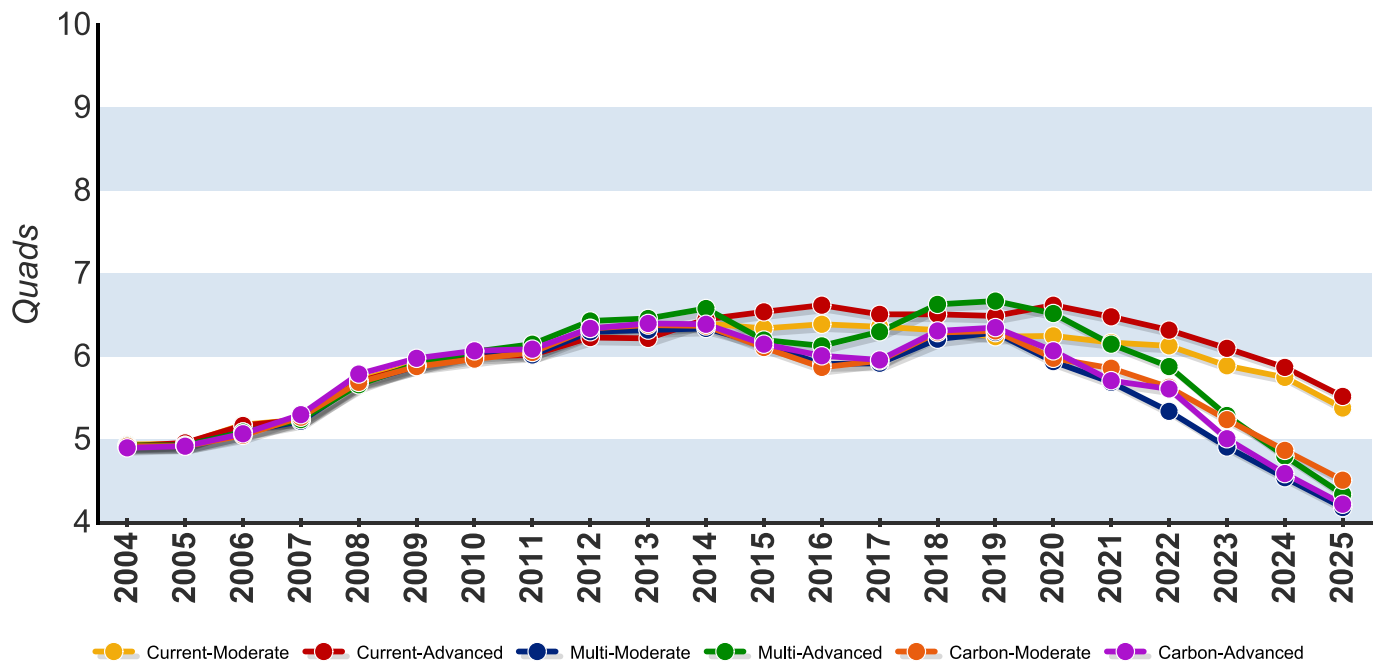


Figure D-19 : Natural Gas Demand-High NG Prices

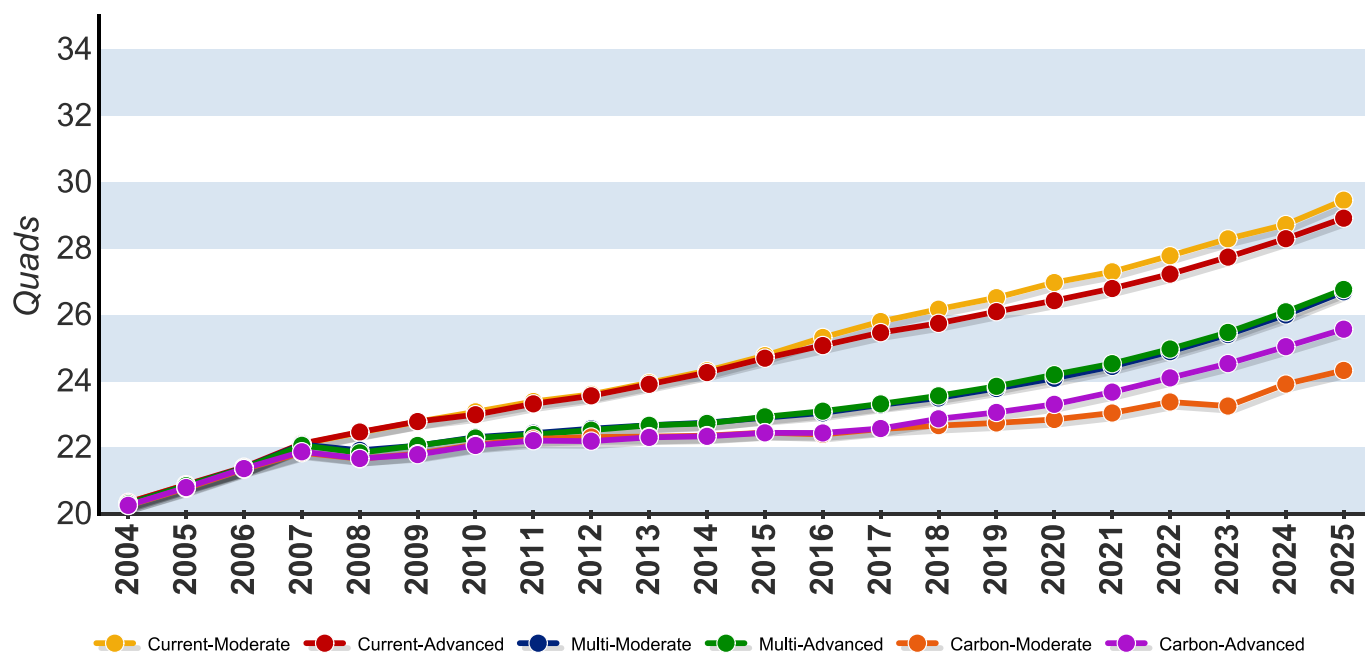


Figure D-20: Coal Demand-Base NG Prices

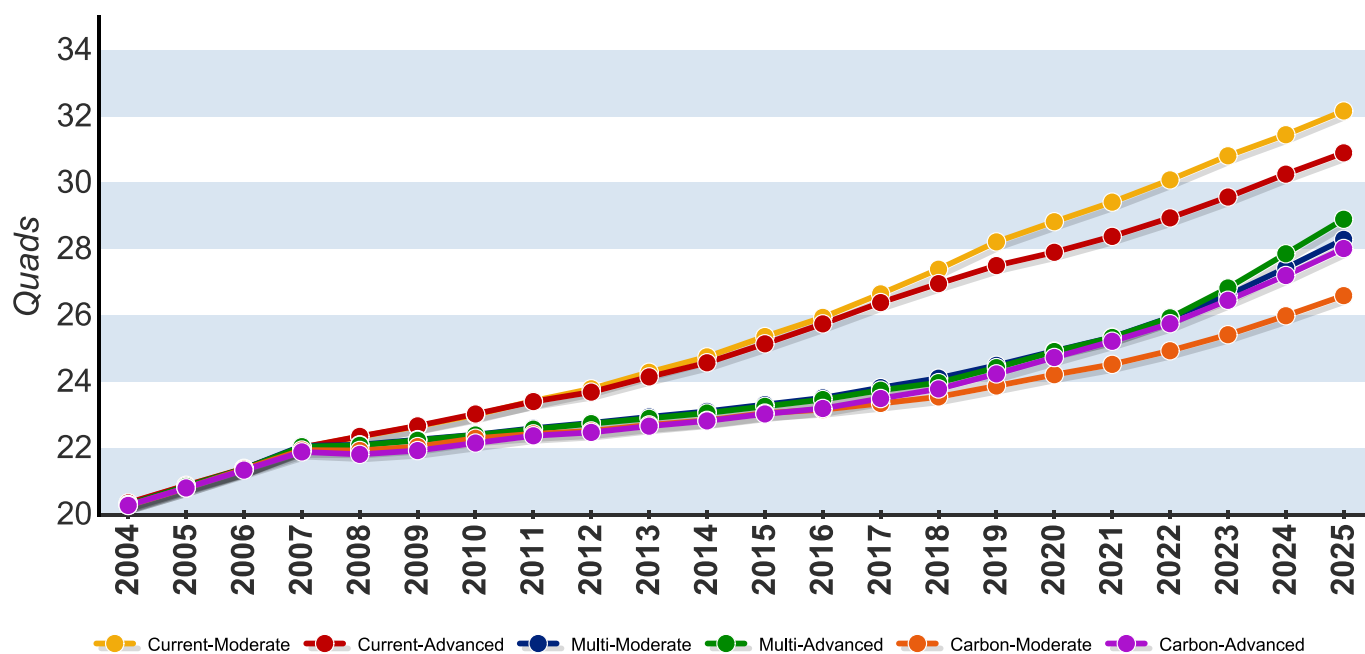


Figure D-21: Coal Demand-High NG Prices

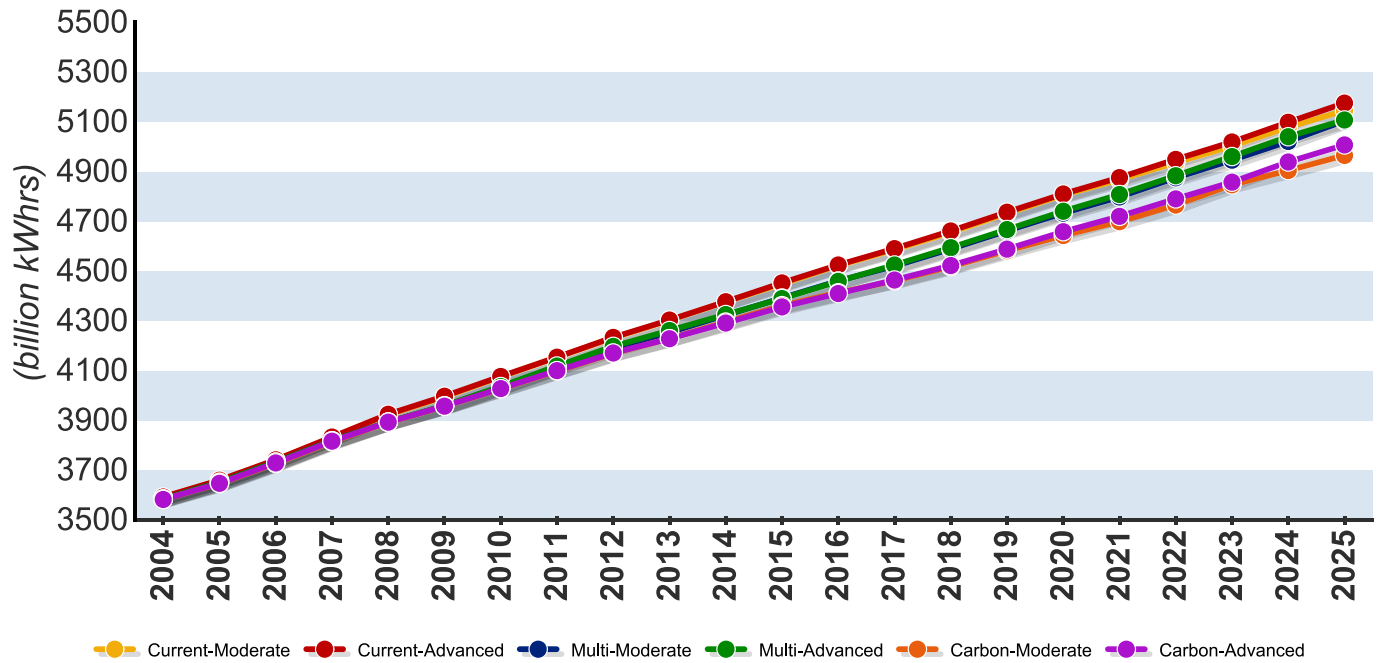


Figure D-22: Electricity Demand-Base NG Prices

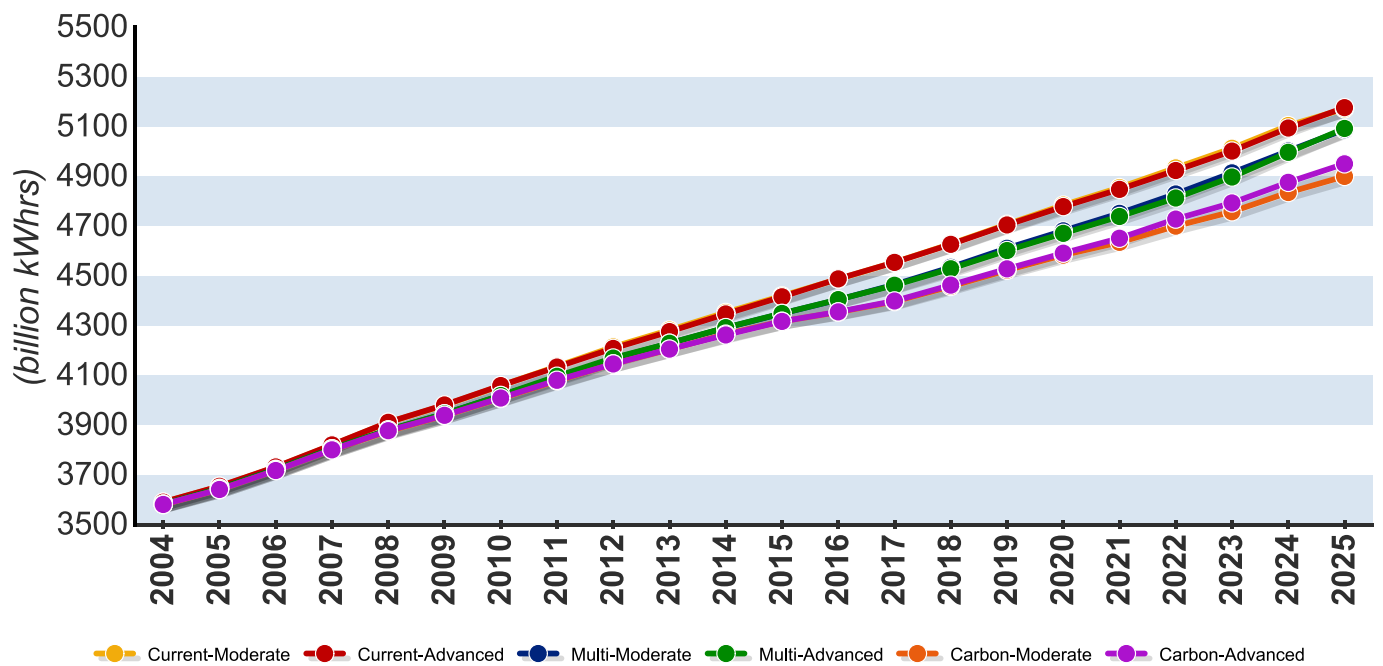


Figure D-23: Electricity Demand-High NG Prices

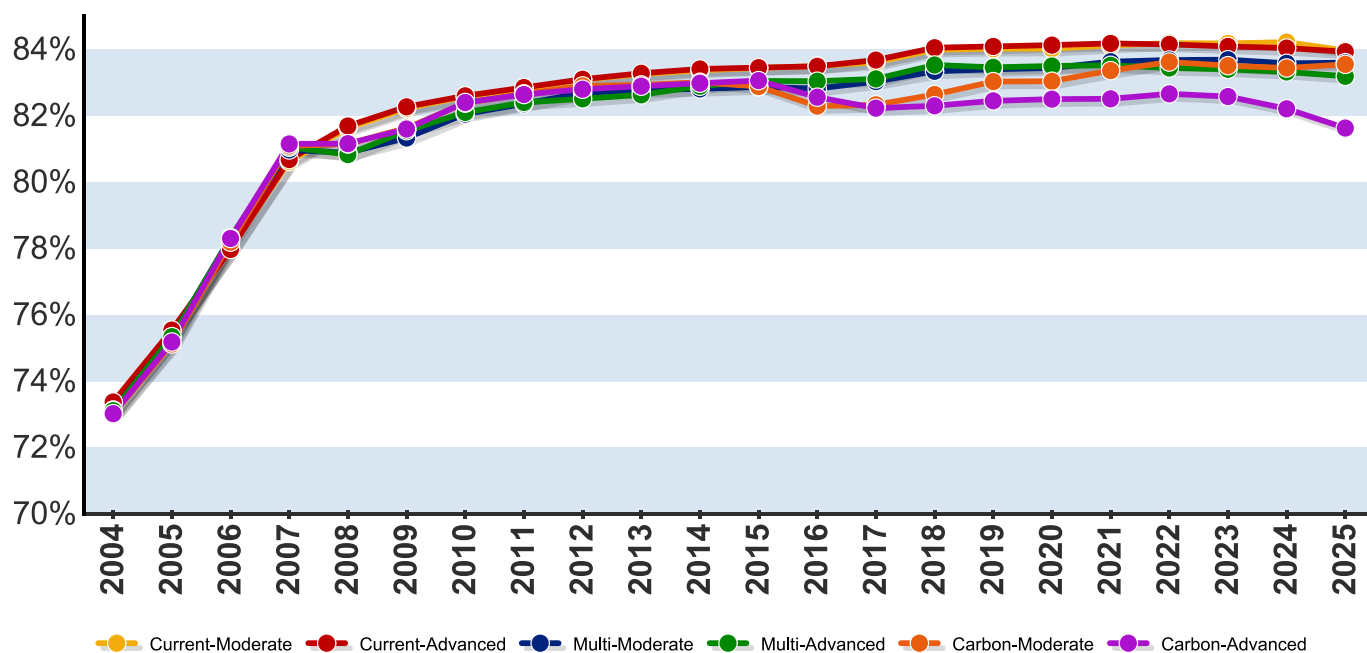


Figure D-24: Coal Capacity Factors-Base NG Prices

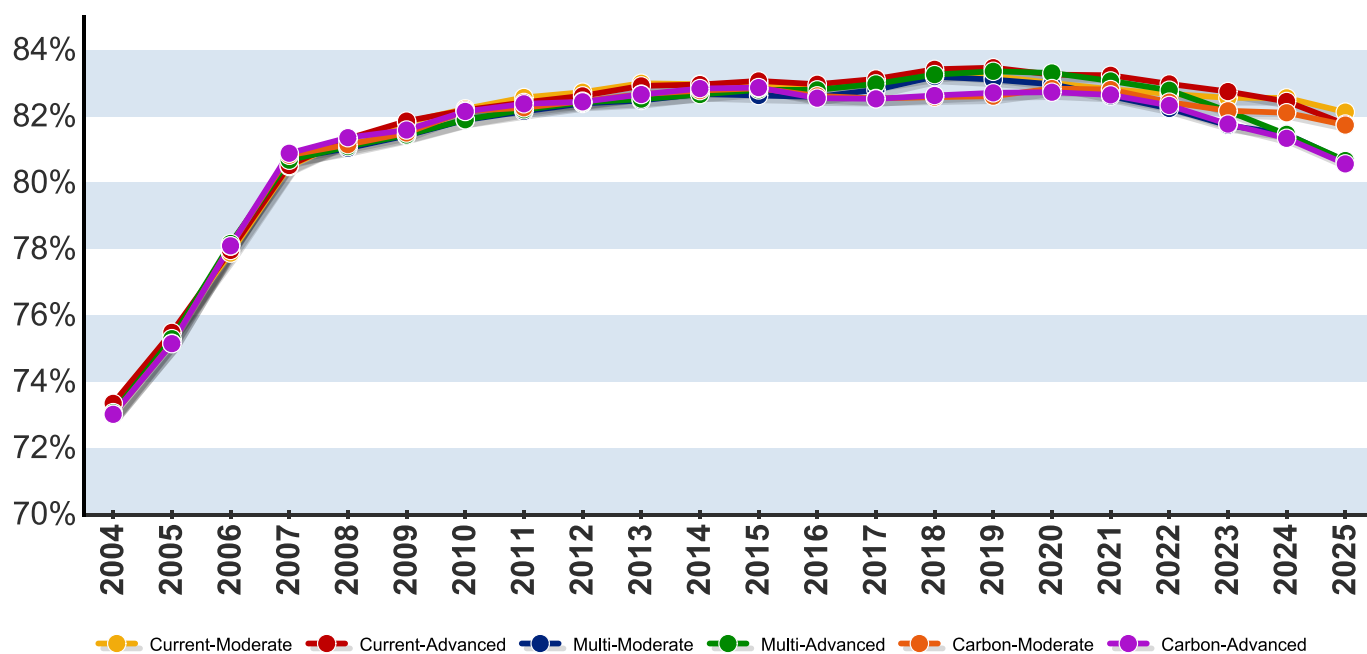


Figure D-25: Coal Capacity Factors-High NG Prices

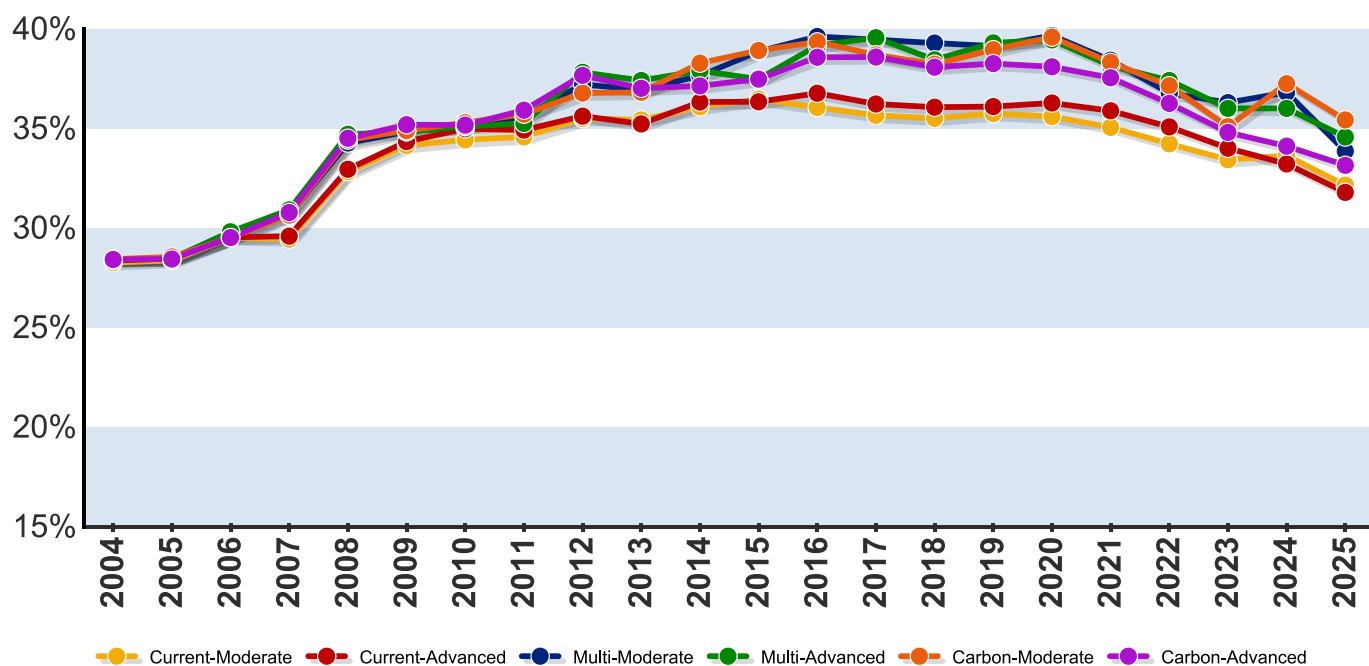


Figure D-26: Natural Gas Capacity Factors-Base NG Prices

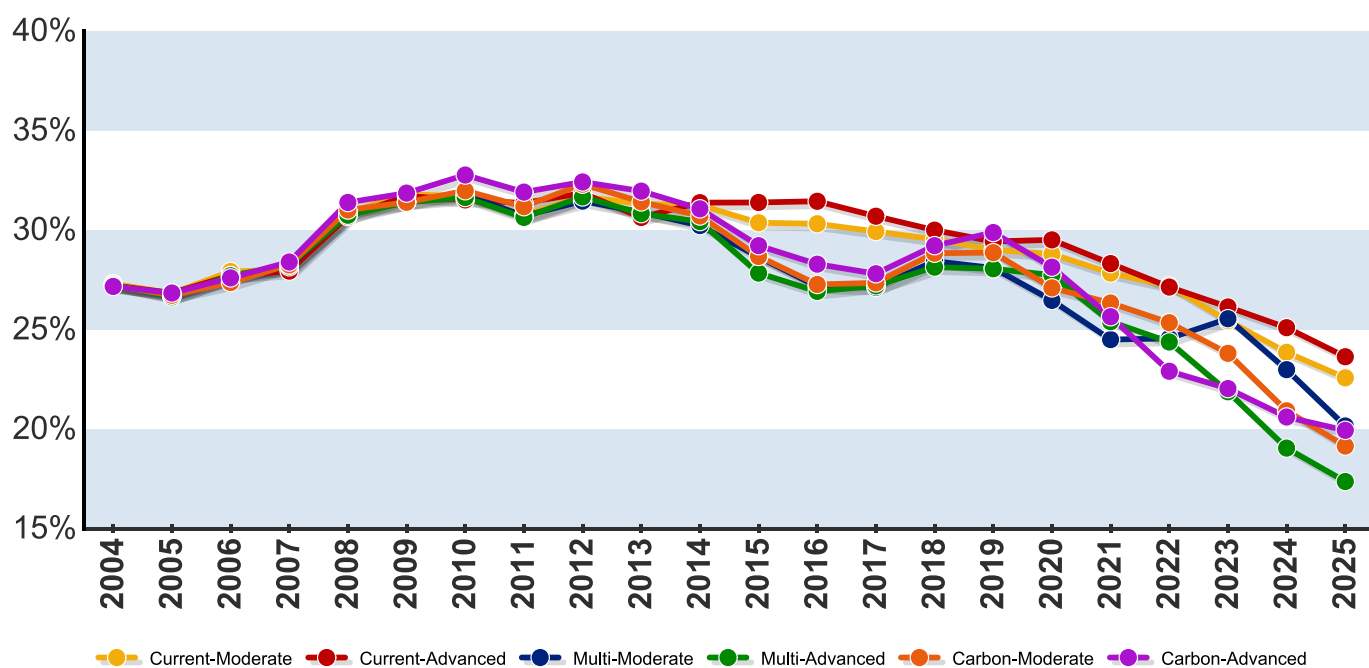
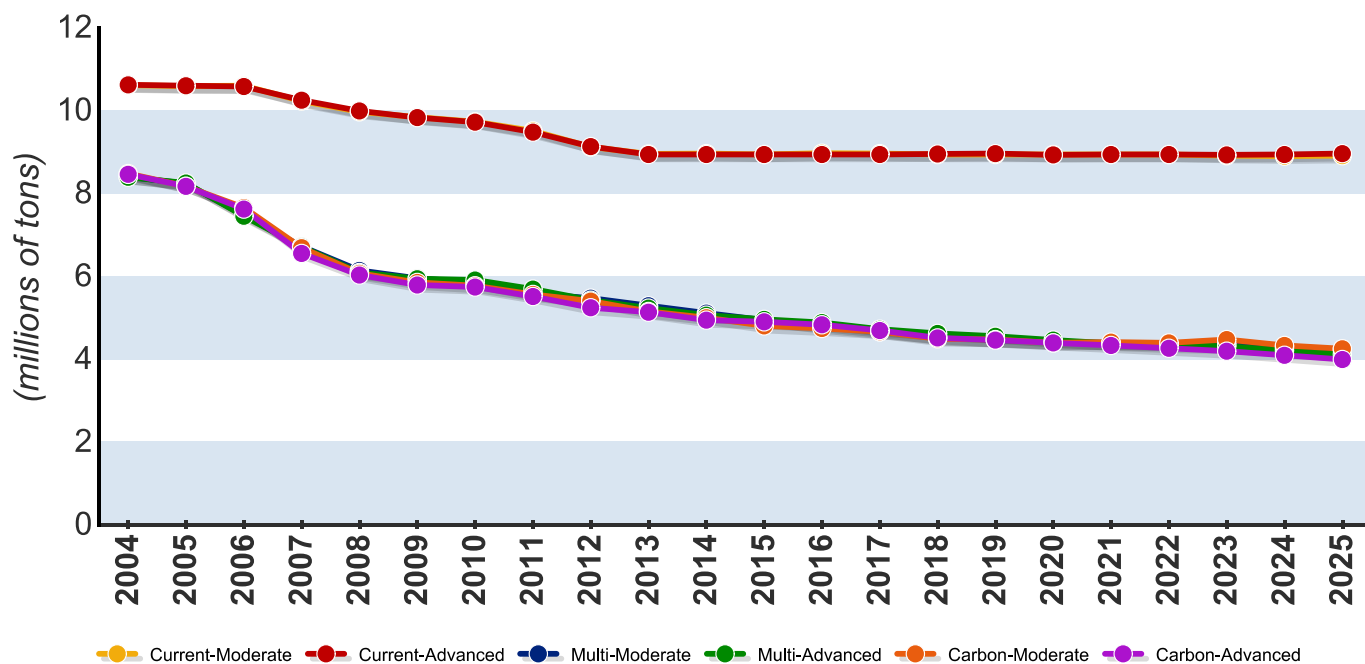
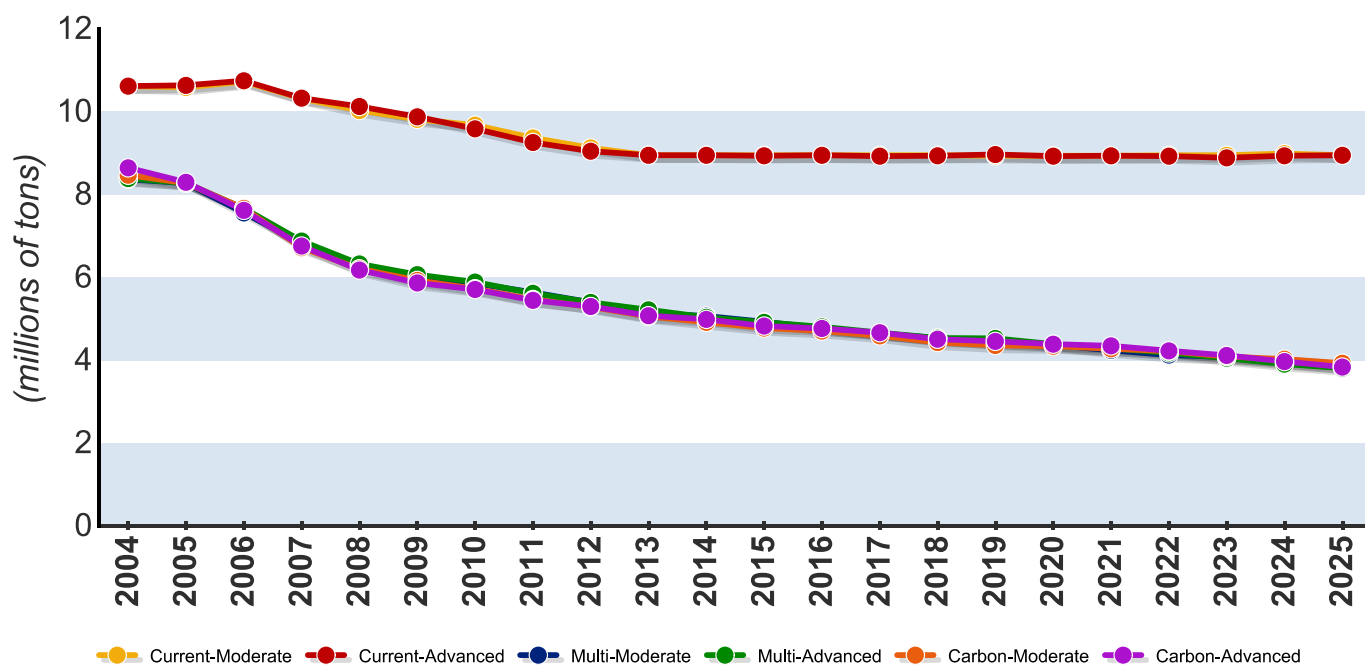
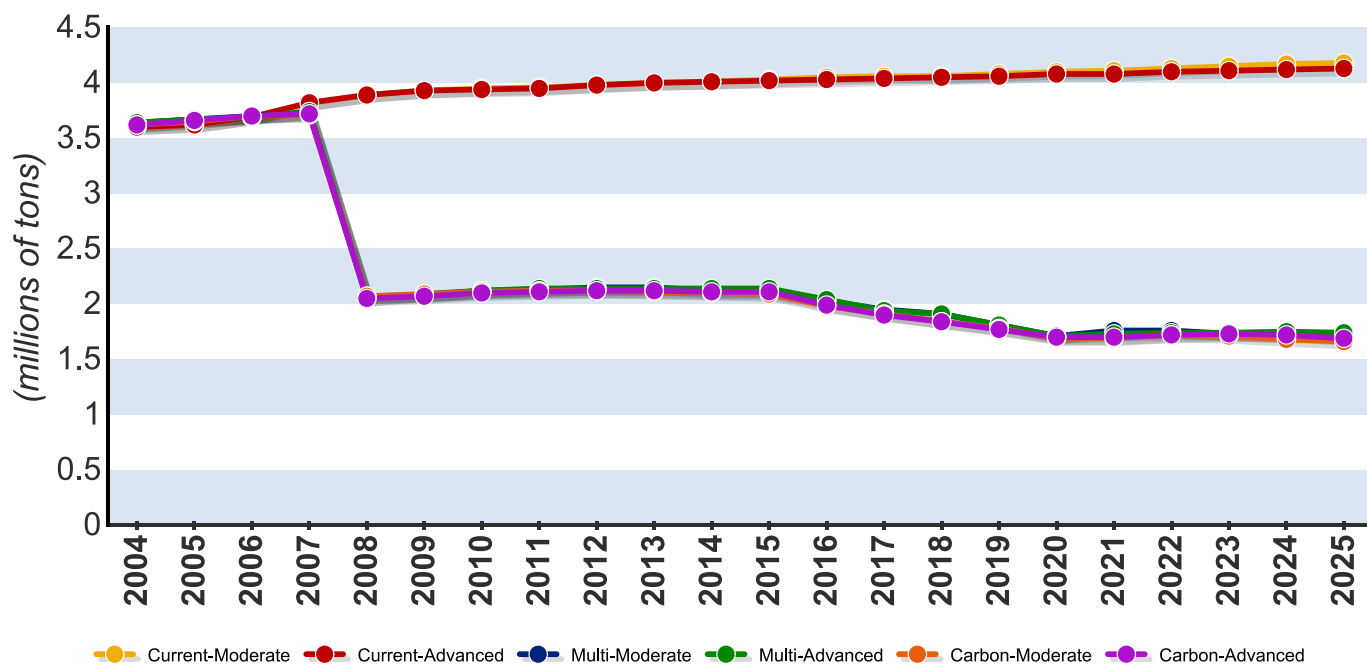
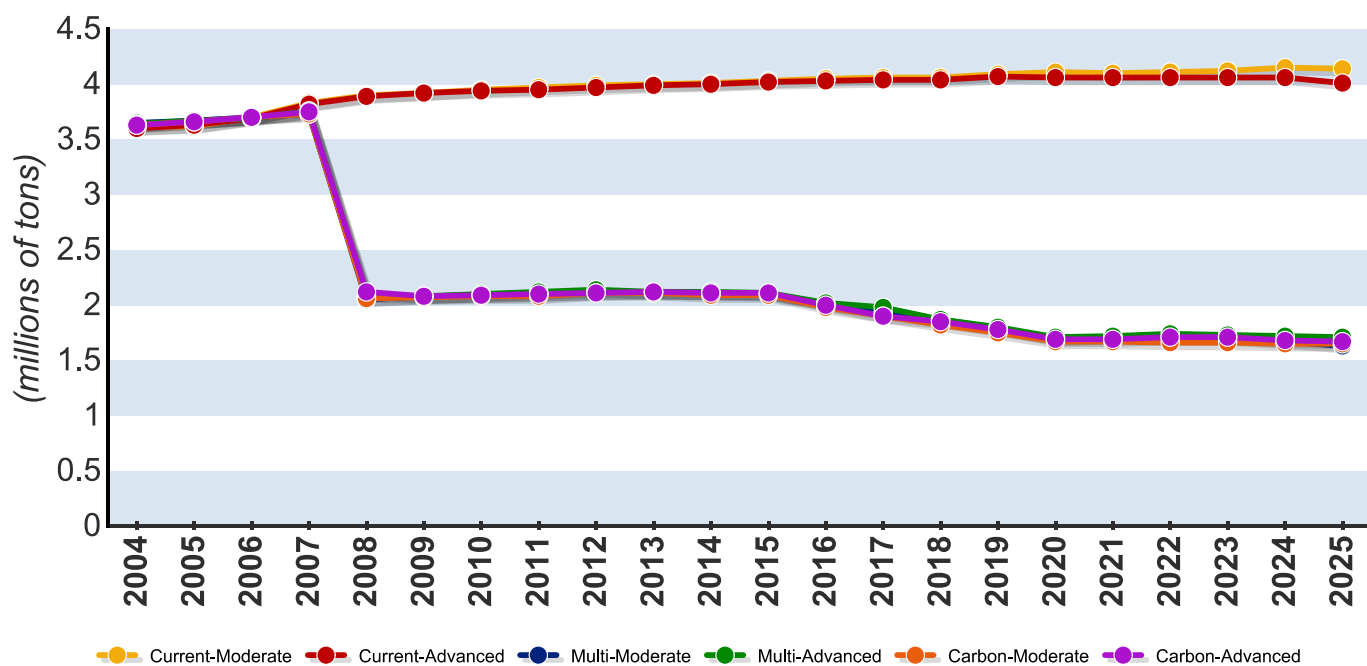


Figure D-27: Natural Gas Capacity Factors-High NG Prices

Figure D-28: SO_x Emissions-Base NG PricesFigure D-29: SO_x Emissions-High NG Prices

Figure D-30: NO_x Emissions-Base NG PricesFigure D-31: NO_x Emissions-High NG Prices

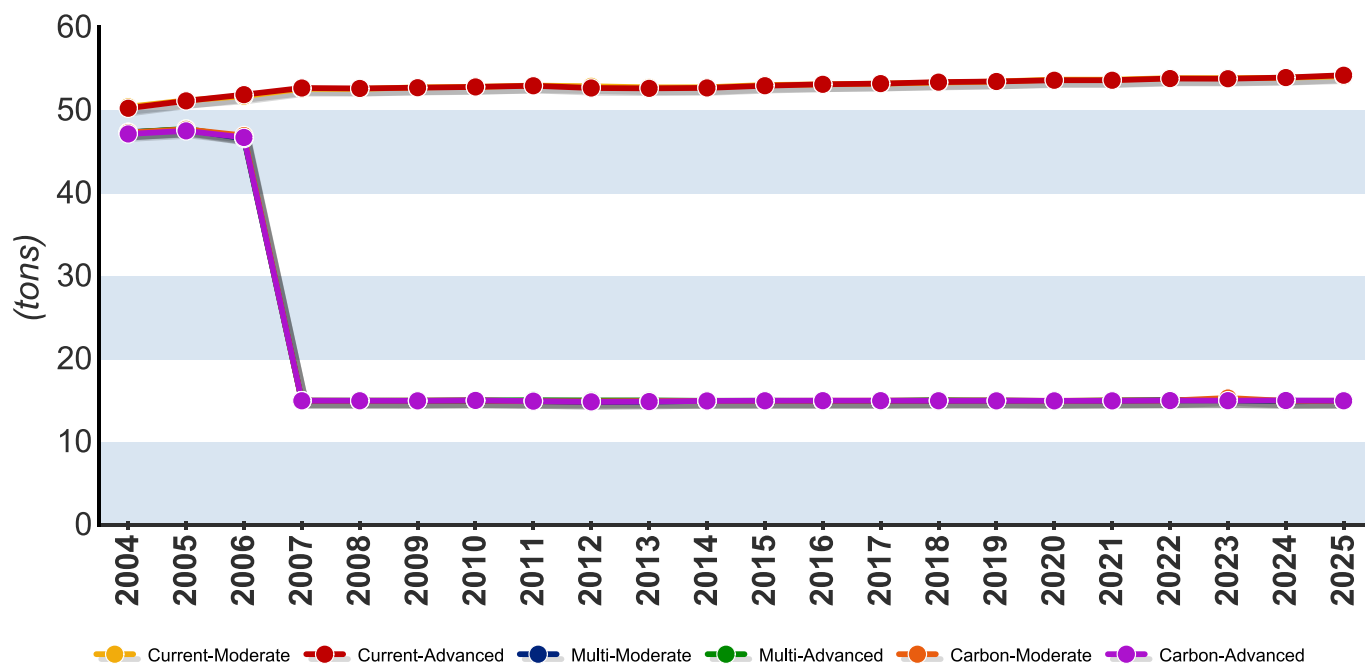


Figure D-32: Hg Emissions-Base NG Prices

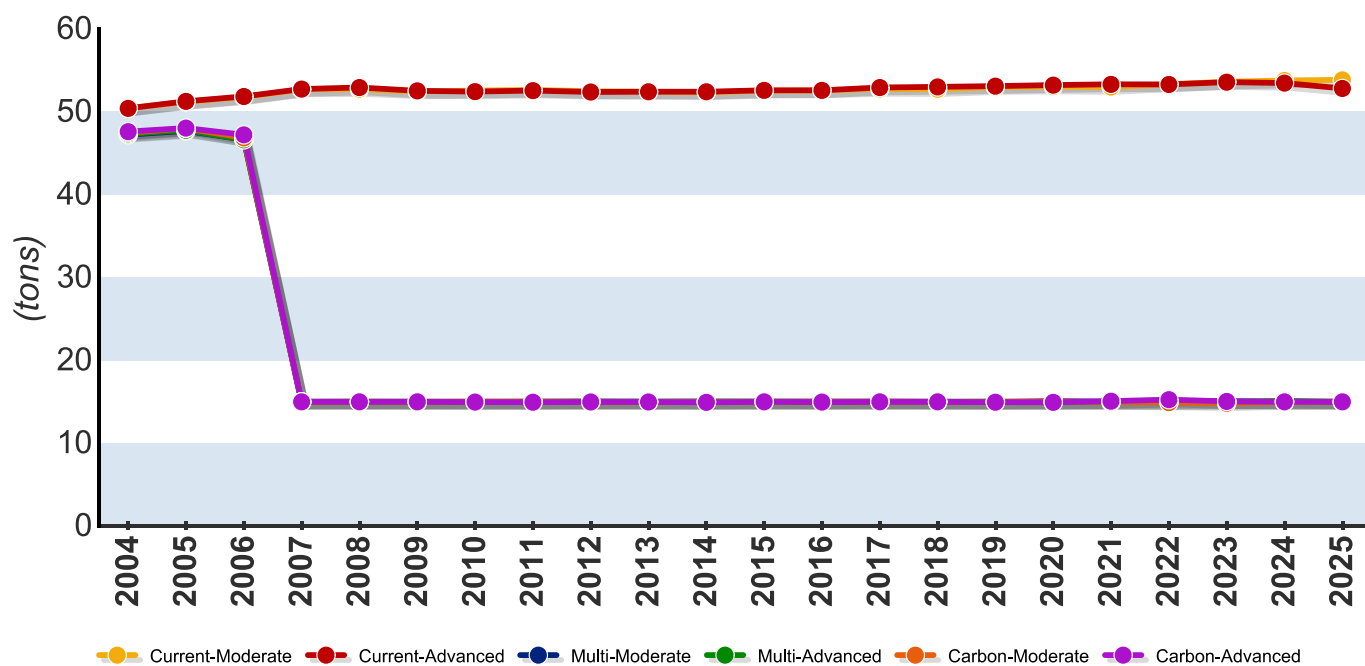


Figure D-33: Hg Emissions-High NG Prices

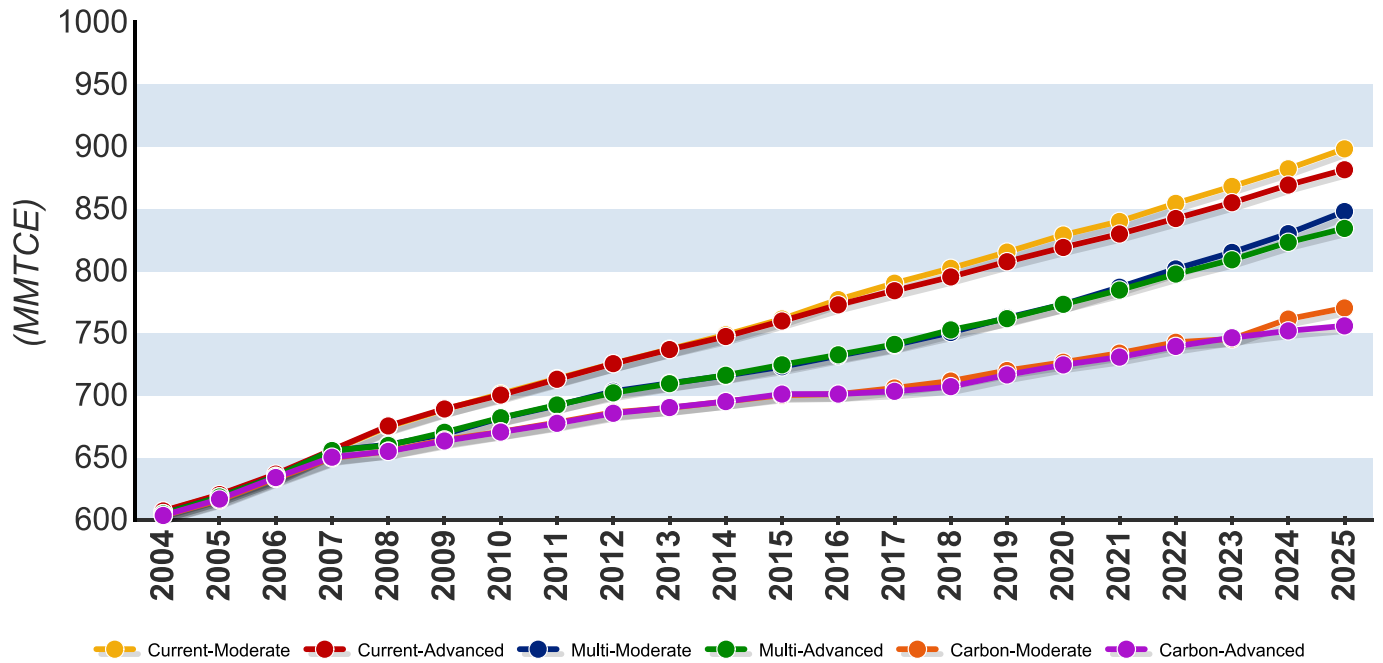


Figure D-34: Carbon Emissions-Base NG Prices

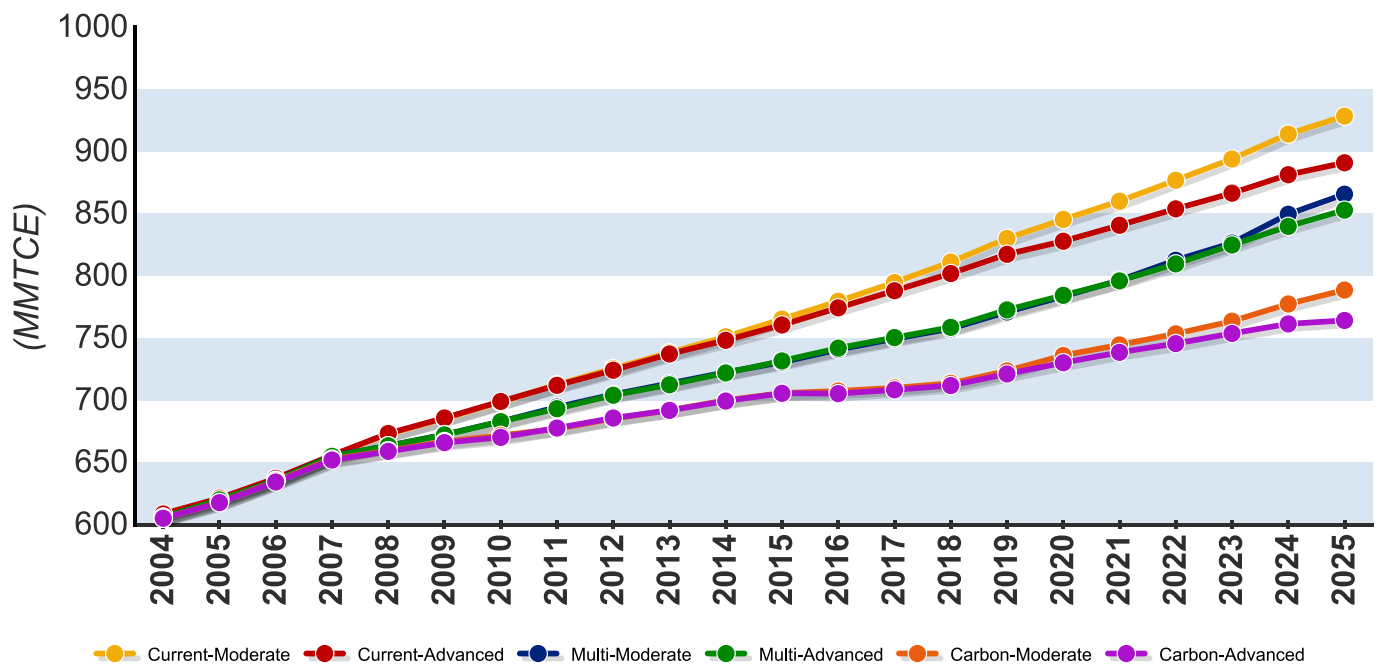


Figure D-35: Carbon Emissions-High NG Prices

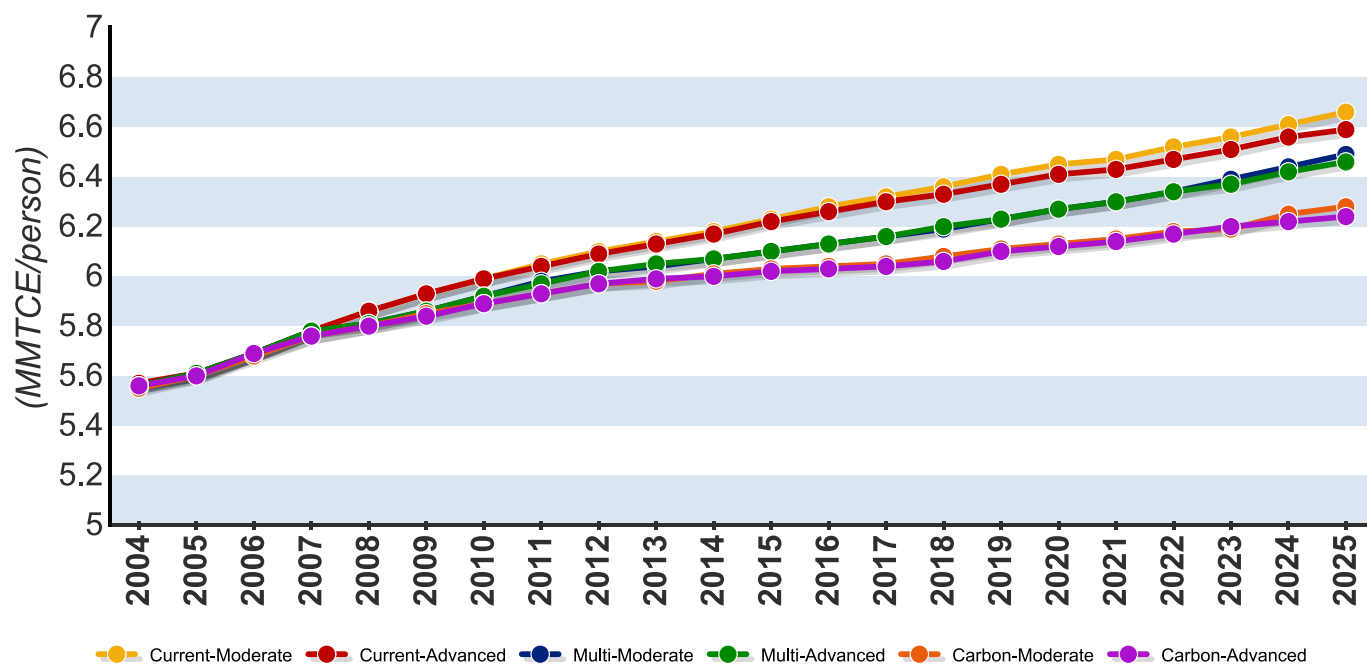


Figure D-36: Carbon per Capita-Base NG Prices

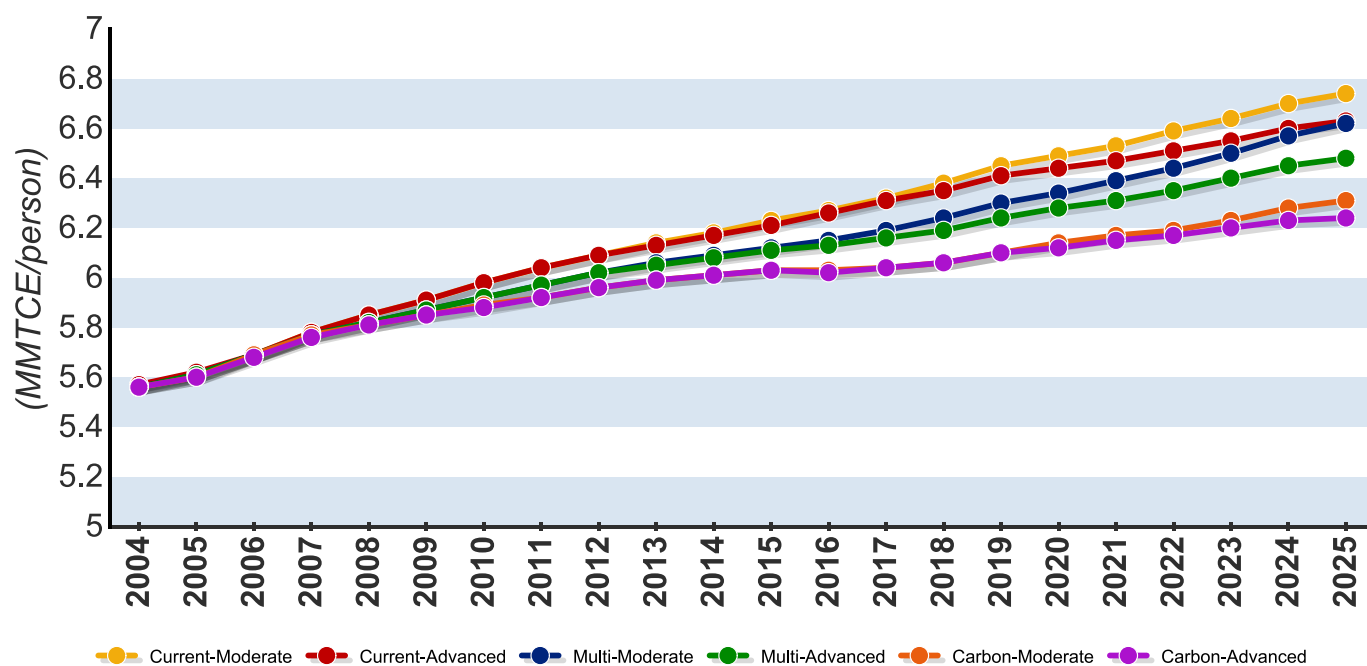


Figure D-37: Carbon per Capita-High NG Prices

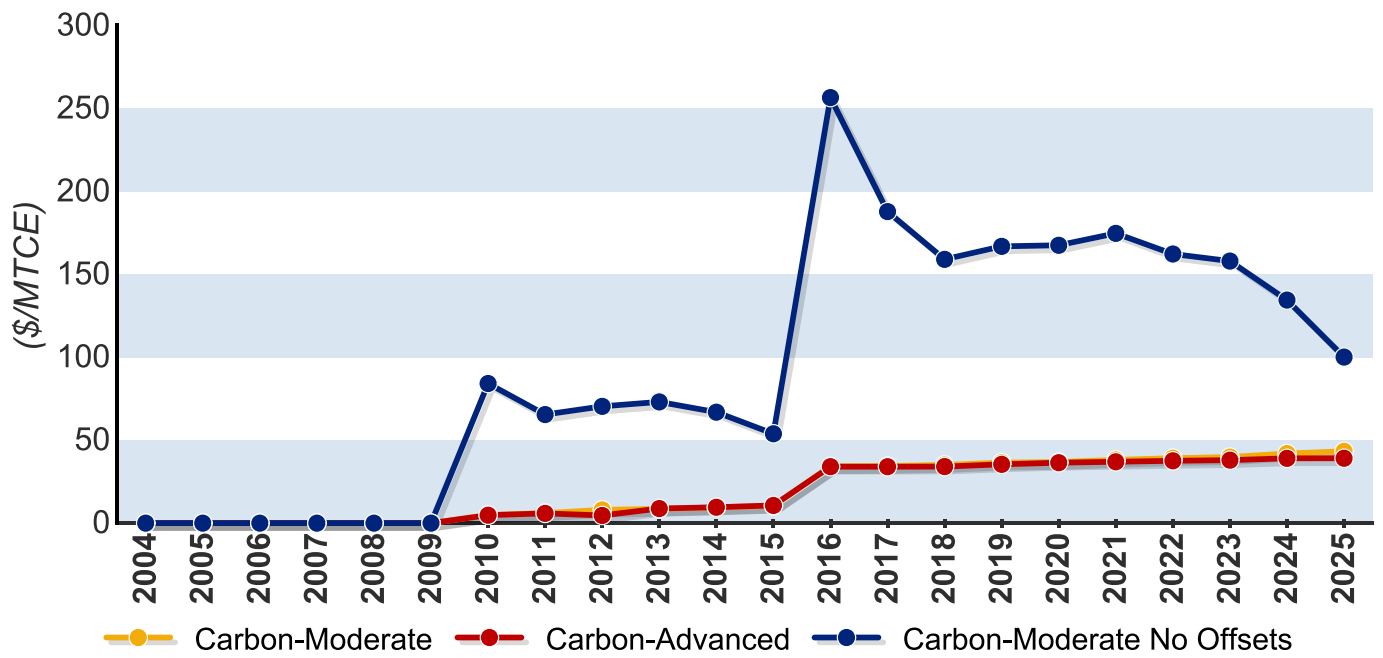


Figure D-38: Carbon Allowance Prices-Base NG Prices

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Appendix E: Survey Results

This appendix contains the results of the surveys that were conducted at the December Workshop and the January Workshop.

Factor/Uncertainty	Mean	Std dev
Capital Cost	4.9	0.3
Performance Wrap/Guarantee	4.5	0.5
Plant reliability	4.4	0.7
Availability	4.2	0.7
Natural gas price volatility	4.2	0.7
Fuel prices	4.1	0.7
Capital market's ability to provide financing	4.1	0.7
Emissions legislation/regulatory uncertainty	3.9	0.9
Electricity prices	3.8	0.8
Electricity overcapacity	3.7	0.9
Capacity factors	3.7	0.7
Forecasted electricity demand	3.7	0.8
Standard plant design	3.6	1.0
Discount rate, hurdle rate, risk premiums, WACC	3.6	0.7
Feasibility of obtaining long-term contracts	3.5	0.6
Technology advancements	3.5	1.0
Variable operating costs	3.4	0.8
Utilities' and merchant generators' credit rating	3.4	0.7
Heat rate	3.4	0.9
Domestic natural gas development	3.3	0.9
New source review	3.2	0.9
Competitor's market position	3.1	1.1
NIMBY - plant view, traffic, trains, property values	3.1	1.1
Fixed operating costs	3.1	0.8
Economies of scale	3.1	0.7
International natural gas development (Canada, LNG, etc.)	3.1	0.7
Power grid market design	3.0	0.5
Plant personnel	3.0	1.0
Fuel flexibility	2.9	1.0
Power technology diversification	2.9	0.7
Coal perception	2.8	0.7
Product flexibility	2.8	0.9
Customer base	2.7	0.9
Forecasted gross domestic product	2.5	1.1
Corporate image	2.5	0.7
Transportation of fuel	2.4	0.7
Hydrogen economy	2.3	
Major disruptions: blackouts, hurricanes, natural disasters	2.3	0.9
Coal price volatility	2.1	1.2

Table E-1: December Workshop Survey Results
Importance of factor or uncertainty to IGCC Market Penetration
(1=unimportant, 5= very important)
N=17

Factor/Uncertainty	Mean	Std dev
Capital Cost	4.7	0.8
Reliability	4.3	0.9
Performance Wraps or Guarantees	4.2	0.9
Availability	4.2	1.0
Fuel Prices	4.1	0.8
Electricity Prices	3.9	1.1
Feasibility of obtaining long-term contracts	3.8	0.8
Capital markets Ability to Provide Financing	3.7	1.1
Natural Gas Price Volatility	3.7	1.0
Regulatory Uncertainty	3.7	0.9
Capacity Factors	3.6	0.8
Discount Rate, WACC, Risk Premiums	3.6	0.9
Economies of Scale	3.5	0.9
Natural Gas Development	3.4	1.0
Forecasted Electricity Demand	3.4	0.7
Standard Plant Design	3.4	0.9
Fixed Operating Costs	3.4	1.0
Heat Rate	3.3	0.8
Variable Operating Costs	3.3	0.9
New Source Review	3.2	0.8
Transmission Grid Capacity Constraints	3.1	1.1
Corporate Image	3.0	0.9
Water Consumption and Treatment	3.0	0.9
Energy Security	3.0	1.1
Market for Byproducts	3.0	0.9
Fuel Diversity	2.9	0.7
NIMBY	2.9	0.9
Coal Perception	2.8	1.0
Fuel Flexibility	2.8	0.9
Product Flexibility	2.7	1.0
Social Corporate Responsibility	2.7	1.1
Early Adopter Advantages	2.5	1.0
Job Creation	2.4	1.1
Hydrogen Economy	2.2	1.2

Table E-2: January Workshop Survey Results
Importance of factor or uncertainty to IGCC Market Penetration
(1=unimportant, 5= very important)
N=29

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